CHEMICAL ENGINEERING

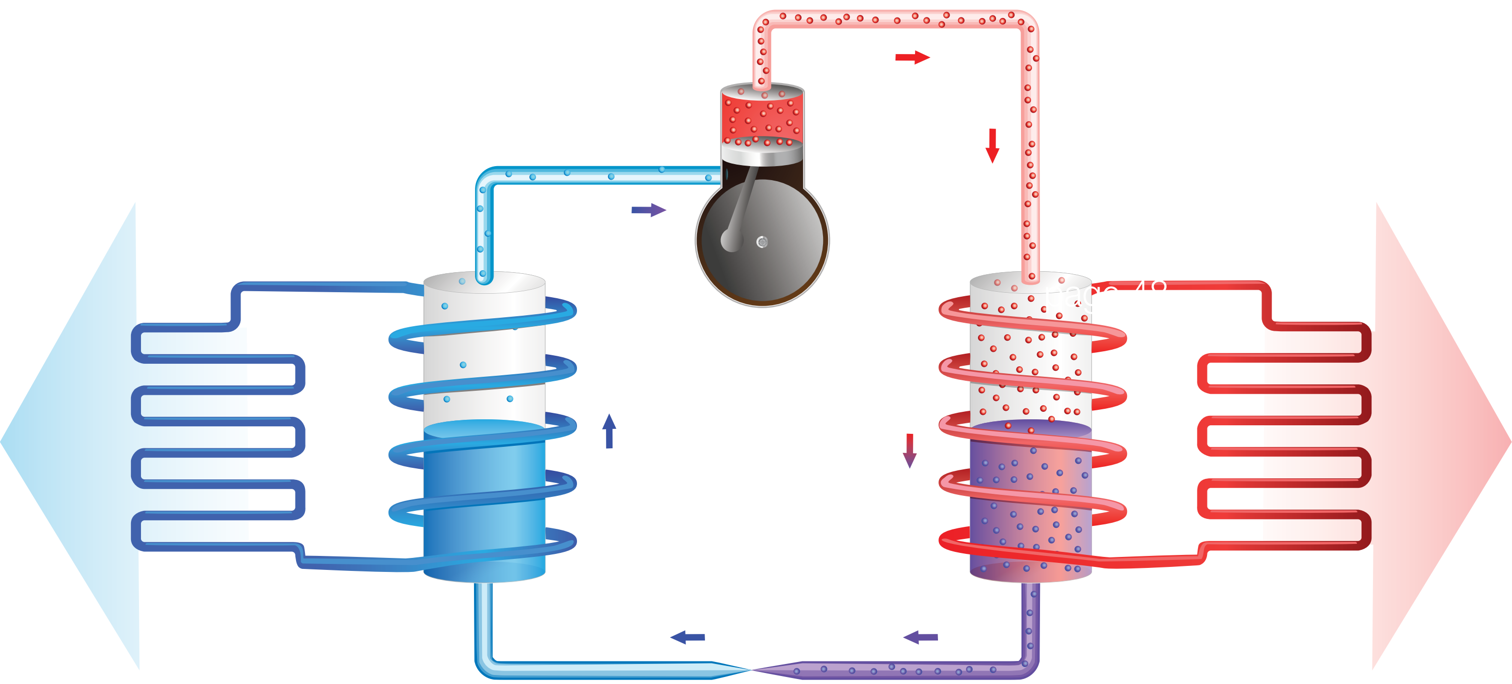
ESSENTIALS FOR THE CPI PROFESSIONAL

www.chemengonline.com

June 2022

Heat Pumps for Energy Efficiency

page 26



Cybersecurity

Membranes

Valve Actuators

Clean-in-Place Systems

Weighing and Dosing

Innovation Strategies

Access Intelligence

CHEMICAL ENGINEERING

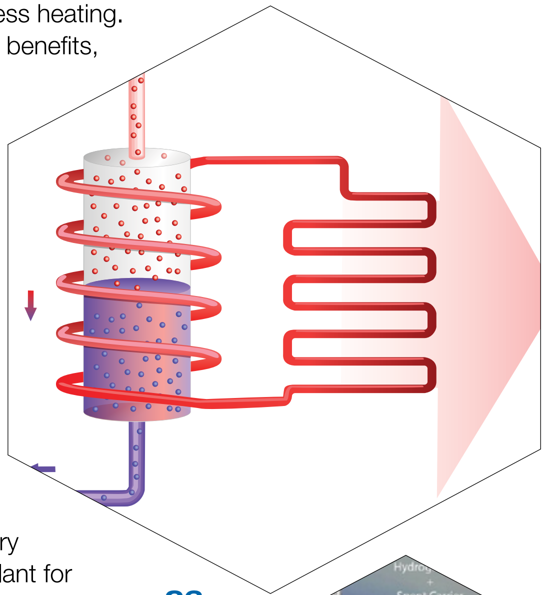
ESSENTIALS FOR THE CPI PROFESSIONAL

www.chemengonline.com

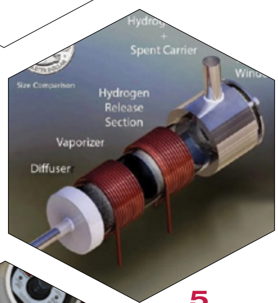
June 2022 Volume 129 | no. 6

Cover Story

In the News



26



5

Technical and Practical

32

37

40

18

21

Equipment and Services

Departments

Advertisers

Chemical Connections

Follow @ChemEngMag on Twitter

Join the *Chemical Engineering* Magazine LinkedIn Group

Visit us on www.chemengonline.com for more articles, Latest News, New Products, Webinars, Test your Knowledge Quizzes, Bookshelf and more

Coming in July

Look for: **Feature Reports** on Pressure Relief; and Materials of Construction; A **Focus** on Pumps; A **Facts at your Fingertips** on Motors & Drives; a **Newsfront** on Smart Supply Chains; **New Products**; and much more

Cover design: Tara Bekman

Editor's Page

Drought emphasizes water scarcity

A megadrought in the U.S. Southwest has triggered emergency measures to be taken, as both water and hydroelectric power supplies to millions of people are threatened. The water levels in the two largest human-made reservoirs in the U.S., Lake Mead and Lake Powell, have been receding for years and have now reached historic lows.

"Bathtub rings" around the reservoir show where water levels have receded. This photo of Lake Powell and the Glen Canyon Dam was taken in 2014, at which time there was already concern about the water levels

The Colorado River Basin

When I visited Lake Powell and Glen Canyon Dam in 2014, the "bathtub rings" around the reservoir allowed for spectacular views of the rock formations (photo). However, the rings were a foreboding sign of the receding water levels, and at that time, there was already concern about the future of the water supply. Lake Powell's water level, which when full is at an elevation of about 3,700 ft, is now at around 3,522 ft — less than 25% of capacity. An elevation of at least 3,490 ft is needed for Glen Canyon Dam to operate and supply power to its over 5 million customers [*1*]. Just last month, for the first time, the federal government announced a delay in the release of water from the Lake Powell reservoir to downstream Lake Mead in order to keep Glen Canyon Dam in operation.

And in Lake Mead, which supplies water to millions of people, the extremely low water level has exposed a water intake valve that has been in operation since 1971 and can no longer be used now. These severe drought conditions have driven officials to enact numerous conservation measures, including limiting water supplies to the Colorado River Basin and outlawing "nonfunctional" grass in areas of Nevada.

Engineering for water security

Water scarcity is a global concern and warnings about severe water shortages are alarming [*2*]. The current water crisis in the Southwest emphasizes the need to keep water conservation a top priority. There are numerous ways in which chemical engineers can contribute to sustainable water practices, such as increasing water efficiency in agricultural and industrial operations, and further developing water re-use and desalination technologies. Further suggestions are outlined in the report "New Directions for Chemical Engineering" by the National Academies of Sciences, Engineering and Medicine (Washington, D.C.; www.nationalacademies.org).

The chemical process industries are making headway with their goals toward sustainable water practices. A recent example is Evonik's first zero-liquid discharge (ZLD) catalyst plant in India (chemengonline.com/evonik-opens-first-zero-liquid-discharge-catalyst-plant-in-india/).

New advances in membrane technologies are addressing challenging conditions to meet ZLD goals, and fouling-resistant membranes are being used in industrial water re-use applications. More on these advances are outlined in our Newsfront, "New Membranes Support Sustainability Trends," on pp. 12–17. ■

Dorothy Lozowski, Editorial Director

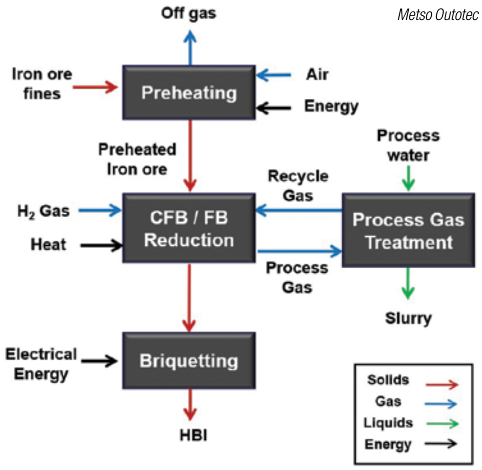
1. Source: U.S. Bureau of Reclamation, Reclamation's drought response actions will boost Lake Powell, www.usbr.gov, May 3, 2022.
2. United Nations website, www.unwater.org/water-facts/scarcity/

Edited by:
Gerald Ondrey

Relaunching a process that uses 100% H_2 for the direct reduction of iron ore

Developed two decades ago, Metso Outotec's (MO; Helsinki, Finland; www.mogroup.com) Circored process is now being reintroduced as a proven way to help decarbonize the ironmaking process. Developed in the 1990s by the former Lurgi Metallurgie (now part of MO) and continually refined, Circored is a hydrogen-based process for the direct reduction of iron-ore fines to produce zero-carbon hot-briquetted iron (HBI) or direct-reduced iron (DRI), which is used in electric-arc furnaces (EAFs) for steelmaking. Circored uses 100% H_2 as the reducing agent, which enables low-temperature operation (below 650°C) and avoids sticking problems associated with alternative DRI processes, says Sebastian Lang, director for Modeling & New Business of the Ferrous & Heat Transfer business line at MO. The process also operates at higher pressure (4 bars), which allows a reduction in equipment and piping sizes, thereby lowering capital expenditures (capex), he says.

Circored is a two-stage reduction system consisting of a circulating fluidized-bed (CFB) reactor, in which the reaction is controlled by interfacial mass transfer, and a bubbling fluidized-bed (FB) reactor, in which the reduction reaction is diffusion controlled (diagram; see more detailed flowsheet in online version at www.chemengonline.com). Ultimately, more than 93% metallization degree is achieved. Circored does not require a pelletizing plant, which is used to prepare iron ore for feeding a blast furnace (to make pig iron) or a shaft furnace (alternate route to DRI/HBI). Also, the metallurgical coke (from coal) used in blast furnaces is eliminated.



Metso Outotec

As a result, CO_2 emissions for Circored — operating with H_2 produced from conventional steam-methane reforming (SMR) as the H_2 source, for example — are about half that generated by traditional blast furnace routes. If "green H_2" is used as reductant and electric energy for process gas heating — dubbed Circored+ — CO_2 emissions are essentially zero. However, the Circored Process is neutral to the origin of H_2.

Circored has already been proven at industrial scale, having been used in a demonstration plant in Point Lisas, Trinidad (*Chem. Eng*., September 1996, p. 25). The plant operated from 1999 to 2005, producing 500,000 ton/yr of HBI. "If you asked me, this plant was erected 20 years too early," says Lang. "Today, the market drivers have dramatically changed, and direct reduction based on H_2 makes more sense than ever before as a solution to decarbonize the steel industry."

MERCURY REMOVAL

Scientists at Flinders University (Adelaide, Australia; www.flinders.edu.au) have further characterized their sulfur-limonene polysulfide polymer (*Chem. Eng.*, December 2015, p. 12) to understand the conditions under which it can be used as a mercury sorbent. In a recent issue of *Physical Chemistry Chemical Physics*, the researchers have demonstrated that silica covered with an ultra-thin coating of poly(S-r-limonene) can, in some cases, capture 99% of mercury ($HgCl_2$) from water within minutes. The polymer is effective over the pH range from 3 to 11. The material is also selective for binding mercury, but not other metal contaminants, such as iron, copper, cadmium, lead, zinc and aluminum. When salt is added to mimic seawater, the mercury uptake rates and capacity are dramatically reduced.

BIOCEMENT

Scientists from Nanyang Technological University, Singapore (www.ntu.

(Continues on p. 6)

Incorporating waste polyethylene into asphalt

An expanding number of products are demonstrating the real-world feasibility of incorporating post-consumer polyethylene (PE) into asphalt paving for roadways and parking lots. The set of demonstration projects — part of the New End-Market Opportunities (NEMO) program, under the auspices of the Plastics Industry Association (Washington, D.C.; www.plasticsindustry.org)— are intended to investigate the benefits of such applications.

In one approach, known as the wet method, recycled plastic is added into the asphalt binder as polymer modifier or asphalt replacement. This requires mechanical mixing and, in some cases, additional compatibilizers to achieve and maintain a homogeneous modified binder blend, according to the National Center for Asphalt Technology (NCAT) at Auburn University (www.eng.auburn.edu), which has collaborated on several of the projects. In another technique, known as the dry method, recycled plastic is incorporated as a solid additive during the manufacturing of the asphalt mixture.

A recent demonstration occurred at the Chevron Phillips Chemical (The Woodlands, Texas; www.cpchem.com) site in Port Arthur, Texas, where a 67,000-ft^2 lot was paved using asphalt into which 191,000 recycled polyethylene bags were blended.

Last year, similar projects were undertaken by Lyondell Basell at its Cincinnati Technology Center and by grocery retailer Meijer in a collaboration with Dow Chemical. Also, Shell Polymers collaborated with Green Mantra on paving with PE-containing asphalt at its new ethane cracking facility in Potter Township, Pa.

According to Andy Brewer, associate director of sustainability and materials at the Plastics Industry Association, the finished asphalt material shows greater strength and stiffening impact, providing better rutting resistance than conventional asphalt when tested on paved surfaces.

edu.sg) have found a way to create biocement from two common waste materials — industrial carbide sludge (a waste product of acetylene production) and urea (from urine).

To make the biocement, carbide sludge is first treated with an acid to produce soluble calcium. Urea is then added to the soluble calcium to form a cementation solution. A bacterial culture is then added and the bacteria break down the urea into carbonate ions, which react with the soluble calcium ions in a process called microbially induced calcite precipitation (MICP). When this reaction occurs in soil or sand, the resulting calcium carbonate generated bonds soil or sand particles together to increase their strength, and fills the pores between them to reduce water seepage through the material. The same process can also be used on rock joints, which allows for the repair of rock carvings and statues.

The soil reinforced with biocement has an unconfined compression strength of up to 1.7 MPa, which is higher than that of the same soil treated using an equivalent amount of cement.

The proof-of-concept research was described in a recent issue of the *Journal of Environmental Chemical Engineering*.

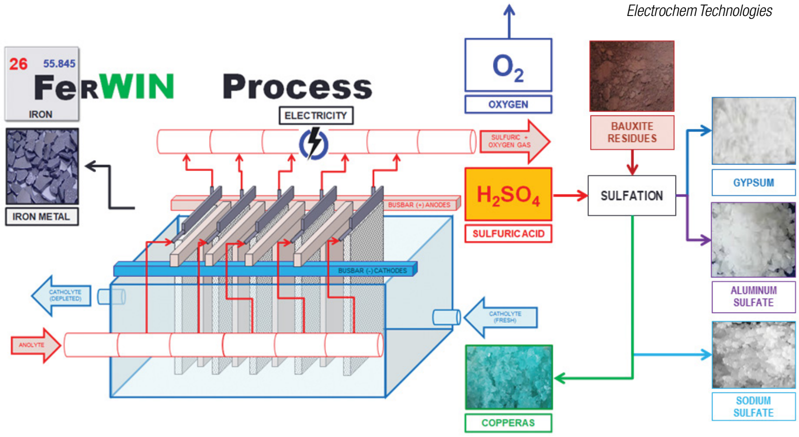
BIOFUEL

Researchers from the University of Agder (UiA; Kristiansand, Norway) and the University of Jaffna (Sri Lanka; www.jfn.ac.lk) are collaborating to develop a more environmentally friendly transportation fuel in Sri Lanka. The biofuel — made from bioethanol and castor oil — is suitable for the engines used in the three-wheeler

(Continues on p. 8)

Recycling bauxite residues and electrowinning iron

Electrochem Technologies



Electrochem Technologies & Materials Inc. (Montreal, Canada; www.electrochem-technologies.com) produced pure electrolytic iron (99.995% Fe) using its patented FerWIN process (diagram) — a sustainable zero-carbon iron-making technology — from ferrous sulfate heptahydrate (copperas) originating from the sulfation of bauxite residues. This pilot test work involved reacting concentrated sulfuric acid with bauxite residues, from which iron, aluminum and sodium sulfates, along with gypsum, are recovered. Then, the electrowinning of iron metal was performed on the crystallized copperas. Pure electrolytic iron flakes were electrowon inside a rectangular electrolyzer with 10 ft^2 of cathodes, while regenerating the concentrated sulfuric acid to be recycled upstream during sulfation.

"Based on the excellent faradic current efficiency (98%), low specific-energy consumption (2.9 kWh/kg Fe) and operating expenditures ($315/m.t. of Fe), we are optimistic that combining the sulfation of bauxite residues and the electrowinning of iron could represent a possible route for neutralizing, dewatering, recycling and valorizing red mud and bauxite residues," says Francois Cardarelli, president of Electrochem Technologies & Materials. "This is particularly true in locations having an oversupply of sulfuric acid from nearby smelters and affordable nuclear power or hydroelectricity," he says.

From an environmental standpoint, the FerWIN process also releases pure oxygen gas to the atmosphere generating carbon tax credits. The patented technology is now granted and enforced in 16 key jurisdictions (within Canada, China, Japan, South Africa, Europe, Brazil and India) where red-mud landfills represent a serious environmental hazard. As the technology is now technically proven, de-risked, and the costs and benefits analysis favorable, the company is currently seeking to secure licensing agreements for the FerWIN process across the aluminum industry, Cardarelli says.

Scaleup project for simultaneous carbon capture and conversion

A multidisciplinary project to scale up a system capable of simultaneously capturing carbon dioxide from fluegas and converting it to ethanol has received $1.9 million from the U.S. Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E; Washington, D.C.; arpa-e.energy.gov). The electrochemical capture-and-conversion process has been proven in a laboratory system designed by Mohammad Asadi, assistant professor at the Illinois Institute of Technology (IIT; Chicago; www.iit.edu) and has the potential to lower the cost of carbon capture to less than $40 per ton of CO_2 (compared to the $60–100 per-ton cost observed today).

To accomplish the one-step capture and conversion, Asadi's laboratory synthesized a catalyst consisting of transition-metals specially functionalized with organic ligands. "We are unifying two problems — capturing CO_2 and converting it to useful chemicals — into one system," Asadi says. The bifunctional material is able to address a number of recalcitrant scientific and engineering challenges, including the mass-transport challenge of bringing CO_2 molecules to a surface, and the thermodynamic challenge of reducing CO_2 while also forming a carbon-carbon bond.

To address the mass transport issue, the nanostructured surface sets up a CO_2 gradient to hasten the diffusion of CO_2 to the reaction surface, where the local environment makes an ethanol-forming electrochemical reaction favorable, Asadi explains.

A multidisciplinary team is now assembled to study the economic feasibility and lifecycle costs of a scaled-up version of the simultaneous capture-and-conversion system. Scaling up the prototype will involve assembling stacks of the electrochemical systems containing the catalyst material, Asadi notes.

"rickshaws" that are a common form of transportation in Sri Lanka and neighboring countries.

First tests of the new fuel — dubbed "Casahol" — have been conducted on a four-stroke motorcycle engine. "The biofuel burned completely, and the oil mixture provided the lubrication the engine needs so as to avoid damage. This makes us optimistic about the development," according to Alfred Christy, professor at UiA's Dept. of Natural Sciences.

PRINTING CARBIDE

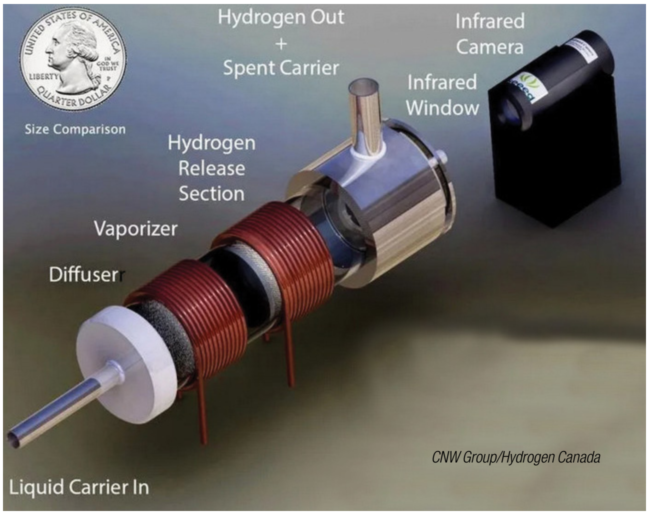
Sandvik AB (Stockholm, Sweden; www.sandvik.com) is expanding its additive-manufacturing offering with the introduction of 3D-printed components in cemented carbide. The new capacity is enabled by a combination of a patented proprietary process and a tailor-made powder that is produced in-house.

Cemented carbide is widely used in, for example, wear-resistant parts across multiple industries, including oil-and-gas, agriculture, machining and food processing. Due to its inherent hardness, the material can be challenging to machine, especially in complex geometries. "Our ability to 3D print cemented carbide on a commercial scale offers customers not only design freedom but also benefits like decreased material waste and longer component life," says Anders Ohlsson, lead product manager at Sandvik's Additive Manufacturing division.

Other hard alloys are often brittle, to some extent, while cemented carbide, with its matrix structure consisting mainly of cobalt and tungsten carbide, is uniquely tough, says

(Continues on p. 9)

Integrated technologies enhance 'green'-ammonia economics



CNW Group/Hydrogen Canada

Ammonia produced using renewable energy is poised to be a crucial part of the hydrogen value chain as a mechanism for storing and transporting hydrogen. By combining two state-of-the art technologies for ammonia production and hydrogen storage, Hydrofuel Canada Inc. (Mississauga, Ont., Canada; www.nh3fuel.com) says it can significantly lower the costs of green H_2 to near-parity with hydrocarbon fuels. The company has licensed the Micro-Ammonia Production System (MAPS) technology developed by researchers at the Georgia Institute of Technology (Atlanta; www.gatech.edu), a gas-phase electrochemical system that mimics the natural nitrogen enzymatic process to produce ammonia from air and water at ambient conditions with high yield and efficiency.

The MAPS process can fully run on renewable electricity, and can provide long-term emissions-free energy storage in the form of liquid ammonia. The process depends on hollow, hybrid plasmonic nanocages, which are said to triple the electrolcatalytic activity of the system (when compared to electrochemical systems utilizing solid catalyst nanoparticles) by increasing the available surface area for reactant contact. A key benefit of MAPS is the decentralization of ammonia production, making it ideal for fueling and energy-storage applications. Ammonia produced via MAPS requires few or no downstream separation or purification.

Coupled with the MAPS process is the patented reactor technology (diagram) developed by Kontak, LLC (Redmond, Wash.; www.kontakhydrogenstorage.com) that enables the highly efficient release of H_2 from NH_3, as well as a dozen other potential carrier molecules. H_2 produced via Kontak's reactor module is filtered and then can be directly sent to a fuel cell or combustion engine. Last year, Kontak was acquired by Hydrofuel Canada.

New catalyst geometry poised to re-shape ethanol-to-ethylene conversion

As chemical manufacturers continue to seek renewable alternatives for fossil-fuel feedstocks, bio-based ethanol is poised to be a crucial raw material in the ethylene value chain for products from jet fuel to plastics. The range of novel-shaped alumina catalyst developed by the Catalysts division of BASF SE (Ludwigshafen, Germany; catalysts.basf.com) is said to enable 99.5% selectivity and conversion for the ethanol-to-ethylene (E2E) conversion process. Later this year, BASF will expand its existing range of E2E alumina catalysts with the addition of a new star-shaped variant.

"Normally, heterogeneous catalysts are offered in tablets or cylindrical extrudates, so this catalyst's unique shape really sets it apart. The fins of the star maximize the active geometrical surface area for the reaction," explains Kaidi Breiten, BASF's global marketing manager for alumina and specialty catalysts. "Another advantage when you go from tablets or regular extrudates to these specially shaped extrudates is that the packed density in the bed, which is correlated with a maximized geometrical surface area, is significantly lower, impacting the overall cost optimization of the reaction," adds Radu Craciun, technology manager for hydrogenation and specialty catalysts with BASF.

Furthermore, says Craciun, the novel geometry correlates to a longer catalyst lifetime because the shape facilitates a beneficial reaction operational temperature and pressure-drop profile. "In a gas-phase process, pressure drop is key, as well as the optimization of the temperature inside the catalyst reactor bed, which is also affected by the shape of the catalyst," he adds. Currently, the new catalyst is undergoing a series of pilot trials with selected BASF customers, with a full commercial launch expected sometime in the third quarter of 2022.

Improved propane dehydrogenation

BASF SE (Ludwigshafen, Germany; www.basf.com) and thyssenkrupp Uhde GmbH (Dortmund, Germany; www.thyssenkrupp-industrial-solutions) achieved measurable improvements in the STAR process, a proprietary dehydrogenation process from thyssenkrupp Uhde that can produce propylene from propane feedstocks, or iso-butylene from iso-butane feedstocks. Beginning in 2020, thyssenkrupp Uhde focused on the optimization and further development of the STAR process, while BASF validated the targeted improvements through an extended test program. The technology has been optimized to reduce CO_2 emissions and operating costs through lower energy consumption by up to 30%, while also reducing investment costs and enabling additional feedstock savings.

ThyssenKrupp Uhde acquired the STAR process and STAR catalyst technology from Phillips Petroleum Co. in 1999. The company subsequently enhanced the process by adding an oxy-dehydrogenation section downstream from the conventional reactor. The STAR catalyst is based on a zinc and calcium aluminate support that, impregnated with various metals, has excellent dehydrogenation properties with high selectivity at near equilibrium conversion and is versatile in its application.

The STAR process (*Chem. Eng.*, January 2014, p. 13) is said to have the highest space-time yields of all propane dehydrogenation technologies, and operates at a reactor exit pressure of approximately 5.8 bars (higher than competing technologies), thereby allowing higher compressor suction pressures, which significantly saves capital and operating expenses on raw-gas compression. Further, compared to other technologies, the STAR process operates at rather mild process temperatures (below 600°C), above which coke formation is more severe and leads to higher de-activation rates of the catalyst. Therefore, the formation of unwanted side products is minimized, says the company.

Global cement industry supports startups in drive to achieve 'net zero' by 2050

Last month, the Global Cement and Concrete Association (GCCA; London, U.K.; https://gccassociation.org) revealed the first six startups that will be backed by its member companies as part of the first ever Innovandi "Open Challenge" in the race to achieve "net zero" CO_2 emissions by 2050. The six start-ups, which were chosen from more than 100 entrants to the Open Challenge, have now joined forces with world-leading cement companies to help drive further innovation in the industry and will each form part of formal consortia to further test, develop and deploy their ground-breaking technologies, says GCCA.

One of the key focuses of the industry is to develop the technology and implementation for carbon capture, utilization and storage (CCUS), with CarbonOrO Products B.V. (Naardem-Vesting, the Netherlands; www.carbonoro.com), MOF Technologies (Belfast, U.K.; www.moftechnologies.com) and Saipem S.p.A. (San Donato Milanese, Italy; www.saipem.com) among the start-ups that the industry is backing. GCCA members have committed to moving from the dozens of pilot projects and announcements already underway to having ten industrial-scale carbon-capture plants by 2030 as part of the landmark Net Zero Roadmap, announced in October 2021. CCUS includes a range of technologies and methods that "capture" CO_2 from large sources — such as in industrial power generation. The CO_2 is then either used on site or compressed and transported to be used or stored elsewhere.

Carbon Upcycling Technologies (Calgary, Canada; www.carbonupcycling.com) and Fortera Corp. (San Jose, Calif; www.forterausa.com) both use captured CO_2 to produce low-carbon cement and cementitious materials. The other confirmed start-up is Coomtech Ltd. (Welney, Norfolk, U.K.; www.coomtech.com), which has developed a low-cost drying technology using kinetic energy created by managed, turbulent air.

Six newly established consortia will help to accelerate the development of technologies that reduce or eliminate carbon throughout the cement and concrete value chain. Each consortium is made up of a startup company, with their respective pioneering technology, and includes between three and eight cement companies, with 16 GCCA member companies involved across the six innovation consortia. ■

the company. Thanks to the extreme durability of the material, the printed components are well suited for most industries looking to optimize production efficiency.

Ohlsson also emphasizes that 3D printing speeds up time-to-market dramatically. Traditionally, cemented carbide is manufactured with powder metallurgy, where a powder is compressed under high pressure into a green body, which is then sintered, explains Ohlsson. "We instead use binder jet technology — we create the green body by fusing the powder with glue. Using conventional component-manufacturing techniques, prototyping can take six to twelve months. Now, our lead time to date is a matter of weeks."

PLANT-REDUCED INDIGO

Archroma (Pratteln, Switzerland; www.archroma.com) and Stony Creek Colors (Springfield, Tenn.; www.stonycreekcolors.com) have entered a strategic partnership to produce and bring to the market Stony Creek's IndiGold high-performance plant-based pre-reduced indigo at scale. Stony Creek extracts its dye from proprietary *Indigofera* plant varieties grown in partnership with family farms as a regenerative rotational crop.

Stony Creek Colors developed the new IndiGold concept as the world's first pre-reduced natural indigo dye, which was then developed with Archroma to offer the first ever plant-based alternative to synthetic pre-reduced indigo. The dyestuff will be sold as a 20% concentration in a soluble liquid form that displays similar performance to comparable synthetic-indigo products available on the market.

Stony Creek Colors evolved into a leader in plant-based indigo due to its complete development of an improved agricultural value chain, from seed breeding and production to biomass harvest and extraction. The company has been selling its U.S.-grown indigo to denim mills since 2015.

Archroma will produce the first batches of IndiGold in Salvatierra, Mexico, and has other locations where the product could be made. The company will support Stony Creek Colors through its manufacturing and logistics capabilities, and its expertise in denim dyeing with customers using pre-reduced indigo. ❒

Business News

LINEUP

- ADNOC
- AGC
- AIR LIQUIDE
- BAKER HUGHES
- BASF
- BOREALIS
- CABOT
- DANIMER
- DOMO CHEMICALS
- EVONIK
- KEMIRA
- LINDE
- OLIN
- ORION ENGINEERED CARBONS
- PETROBRAS
- PHILLIPS 66
- PLUG POWER
- SOLVAY

Look for more latest news on chemengonline.com

Plant Watch

Petrobras to construct new diesel hydrotreating unit at Replan refinery

May 12, 2022 — Petrobras (Rio de Janeiro, Brazil; www.petrobras.com.br) announced that it signed a contract with the Toyo Setal HDT Paulínia Consortium, formed by the companies TSE and Toyo, for the construction of a new diesel hydrotreatment unit at the Paulínia Refinery (Replan). The investment in the new unit will be $458 million, and when the plant starts up operations (expected in 2025), Replan will be able to increase its production of S-10 Diesel by 63,000 barrels per day (bbl/d) and jet fuel by 12,500 bbl/d.

Phillips 66 makes progress to convert refinery to produce renewable fuels

May 12, 2022 — Phillips 66 (Houston; www.phillips66.com) made a final investment decision to move forward with a project to convert its San Francisco Refinery in Rodeo, Calif. into one of the world's largest renewable-fuels facilities. The project is expected to cost approximately $850 million and begin commercial operations in the first quarter of 2024. Upon completion, the converted facility will process used waste oils, fats, greases and vegetable oils to produce 800 million gal/yr of renewable transportation fuels.

BASF to expand production capacities for methane sulfonic acid in Ludwigshafen

May 6, 2022 — BASF SE (Ludwigshafen, Germany; www.basf.com) has invested in the expansion of production capacities for methane sulfonic acid (MSA) at the *Verbund* site in Ludwigshafen. This investment increases capacity at the site to a total of 50,000 metric tons per year (m.t./yr).

Orion to build new production plant for acetylene-based conductive additives

May 6, 2022 — Orion Engineered Carbons S.A. (Luxembourg; www.orioncarbons.com) plans to build the only plant in the U.S. producing acetylene-based conductive additives, which are used in lithium-ion batteries and high-voltage cables. To be located in La Porte, Tex., the plant will receive between $120 million and $140 million in investment from Orion, and is expected to start up in the second half of 2024. The investment should increase the company's conductive additives capacity by approximately 12,000 m.t./yr.

AGC to increase chlor-alkali production capacity in Thailand

May 6, 2022 — AGC Inc. (Tokyo, Japan; www.agc.com) will increase the production capacity of its chlor-alkali subsidiary AGC Vinythai Public Co. The capacity increase is planned at two manufacturing sites in Thailand, and the start of operation is scheduled for early 2025. The total investment is expected to exceed ¥100 billion (around $780 million). With this expansion, AGC's annual production capacity of chlor-alkali products in Southeast Asia will increase to 1.64 million m.t./yr of caustic soda, 1.7 million m.t./yr of vinyl chloride monomer (VCM) and 1.6 million m.t./yr of polyvinyl chloride (PVC).

DOMO Chemicals expands polyamide production capacity in China

May 2, 2022 — DOMO Chemicals GmbH (Leuna, Germany; www.domochemicals.com) is investing to expand production capacity of Technyl-branded polyamide at its production site in Jiaxing, China. Since March 2022, an additional 6,000 m.t./yr of capacity is available at the site. A new, 35,000-m.t./yr plant is planned to be completed in the third quarter of 2023, in which DOMO Chemicals has invested more than €14 million. DOMO Chemicals will further expand the plant, gradually increasing its capacity to 50,000 m.t./yr.

Air Liquide to build a new ASU for EZZ Steel in Egypt

May 2, 2022 — Air Liquide S.A. (Paris; www.airliquide.com) and steel producer EZZ Steel (Cairo, Egypt) have signed a new longterm agreement for the supply of industrial gases to EZZ's new plant in Ain Sokhna, Egypt. Air Liquide Egypt will invest around $80 million dollars in building an air separation unit (ASU) to supply EZZ with 770 m.t./d of oxygen.

Cabot to build new production line for aqueous pigment dispersions

April 28, 2022 — Cabot Corp. (Boston, Ma.; www.cabotcorp.com) is expanding its manufacturing facility in Haverhill, Mass. with the addition of a new production line for color aqueous pigment dispersions. The project is part of an ambitious investment program of more than $50 million over the next three years to meet the growing demand of the inkjet market for digital printing applications. It is expected that the new line will be operational in 2023.

Linde to increase U.S. helium supply with new processing plant in Texas

April 25, 2022 — Linde plc (Guildford, U.K.; www.linde.com) signed a new helium offtake agreement to recover the helium contained in Freeport LNG's production site in Texas. Linde will also construct a new helium processing plant in Freeport to purify and liquify the recovered helium, securing an additional source of liquid helium in the U.S. The project is slated to start up in 2024 and provide nearly 200 million ft^3 of helium into Linde's supply portfolio.

Mergers & Acquisitions

Evonik outlines strategic plan to exit Performance Materials sector

May 11, 2022 — As a part of the next phase of its strategic transformation, Evonik Industries AG (Essen, Germany; www.evonik.com) is aligning its portfolio completely into three divisions: Specialty Additives, Nutrition & Care and Smart Materials. Preparations are already underway to exit of all three businesses of the Performance Materials unit: Superabsorbents, Functional Solutions and Performance Intermediates. Evonik aims to find new owners or partners for each of these three businesses in the course of 2023.

Solvay takes full ownership of soda ash JV in Wyoming

May 4, 2022 — Solvay S.A. (Brussels, Belgium) announced the \$120-million acquisition of the 20% minority stake held by AGC in the companies' soda ash joint venture (JV) located in Green River, Wyoming. Solvay and AGC formed the JV in 1992. The facility, operated by Solvay, produces soda ash and sodium bicarbonate from trona.

Danimer and Kemira partner on bio-based coatings development

May 3 — Danimer Scientific, Inc. (Bainbridge, Ga.; www.danimerscientific.com) and Kemira Oyj (Helsinki, Finland; www.kemira.com) announced a multi-year license and supply agreement to commercialize bio-based barrier coatings for paper and board products based on polyhydroxyalkanoate (PHA) biopolymers. The companies will introduce the new coatings in food-and-beverage industry applications.

ADNOC to acquire 25% stake in Borealis

May 2, 2022 — Abu Dhabi National Oil Co. (ADNOC; www.adnoc.ae) and Mubadala Investment Co. announced a strategic transaction under which ADNOC will acquire a 25% shareholding in Borealis AG (Vienna, Austria; www.borealisgroup.com) from Mubadala. Upon completion of the transaction, which is subject to customary closing conditions and regulatory approvals, Borealis will be owned 25% by ADNOC and 75% by OMV AG (Vienna, Austria; www.omv.com).

Plug Power and Olin to create green-hydrogen JV

April 29, 2022 — Plug Power Inc. (Latham, N.Y.; www.plugpower.com) and Olin Corp. (Clayton, Mo.; www.olin.com) are creating a JV to produce and market green hydrogen throughout North America. The JV's first production plant in St. Gabriel, La. will produce 15 m.t./d of green hydrogen. The JV is expected to be operational in 2023.

Baker Hughes acquires CO_2-capture firm Mosaic Materials

April 25, 2022 — Baker Hughes Co. (Houston; www.bakerhughes.com) has acquired Mosaic Materials Inc. (Alameda, Calif.) to further develop and scale its next-generation capture technology for CO_2 reduction from stationary sources and CO_2 removal from the atmosphere. Mosaic's metal-organic framework technology is a proprietary adsorbent material that acts like a molecular sponge to selectively capture CO_2 across many value chains, including refining, shipping, steelmaking and cement manufacturing. ■

Mary Page Bailey

New Membranes Support Sustainability Trends

Advances in membrane technologies allow processors to delve into gas- and water-separation applications more effectively and efficiently

Conventional membranes have a reputation for being "finicky" and "high maintenance" because they don't operate well under high pressures or temperatures, are subject to fouling and consume significant amounts of energy. However, growth in gas- and water-separation applications has led to the development of more robust membranes with higher fouling resistance and enhanced selectivity, both solving problems and opening avenues for new applications driven by sustainability trends, including a green gas economy and water conservation.

"Membrane systems get a bad reputation for being picky or needy with the water quality they are able to accept, as well as for fouling and scaling that leads to increased cleaning, frequent membrane replacement and, ultimately, unplanned downtime," says Jared Galligan, director of engineering with Kurita America, Inc. (Minneapolis, Minn.; www.kuritaamerica.com). "But, as water conservation and reuse and other sustainability practices become standard operating procedure, membranes will be playing a bigger role, so current users are demanding more robust and reliable operation from their membrane systems, and providers of membranes and membrane systems are working on developments to support these needs" (Figure 1).

Innovating for robustness

"In many applications, especially in gas separations, the membrane requires an enormous robustness," explains Goetz Baumgarten, vice president of membranes at Evonik Industries AG (Essen, Germany; www.evonik.com). "Membranes for these types of applications are made of high-performance polymers, which offer fantastic gas-separation abilities. But if you have separation of natural gas where conditions of high temperatures, high pressures and organic liquids are present, you need membranes that can operate under these harsh conditions."

FIGURE 1. As water conservation and other sustainability practices become standard, membranes will be playing a bigger role. Providers of membranes and membrane systems are developing more robust and reliable components and systems

Baumgarten says more robust membranes are becoming essential as we move toward a sustainable gas economy because they are needed for applications in hydrogen extraction and other green-gas processes. And, Evonik, he says, is developing membranes for these types of applications (Figure 2). "For example, we identified the need to extract hydrogen from natural gas grids because as the world heads towards a hydrogen economy, we need the ability to transport hydrogen in its own pipeline systems in the future," says Baumgarten. "However, currently, most of the globe uses natural gas pipeline grid infrastructure. To take advantage of the existing infrastructure, we partnered with Linde Engineering [Pullach, Germany; www.engineering.linde.com] to

Evonik Industries

FIGURE 2. More robust membranes are becoming essential as we move toward a sustainable gas economy because they are needed for applications in hydrogen extraction and other green gas processes. Evonik is developing membranes for these types of applications

develop hydrogen-extraction technology, which enables existing infrastructure to transport hydrogen next to natural gas and extract the hydrogen where it is needed at a grade that is required by the customer."

This technology is a combination of Evonik's membrane technology and Linde's pressure-swing adsorption (PSA) technology. Linde recently launched a full-scale pilot plant in Dormagen, Germany, to demonstrate how hydrogen can be separated from natural gas streams. The process is a key enabler for scenarios in which H_2 is blended with natural gas and transported via natural gas pipelines. The blended gas can consist of between 5 and 60% H_2. Membranes are then used to extract H_2 from these natural gas streams at the point of consumption. The resulting hydrogen has a concentration of up to 90%. When further processed with Linde's PSA technology, a purity of up to 99.9999% can be achieved.

The high-performance membrane package unit is based on a robust polymer developed by Evonik. It consists of highly selective hollow fibers that efficiently separate the H_2 in the blended natural-gas stream from the main components of methane and higher hydrocarbons. The membrane material is particularly robust, as natural gas contains a host of other substances that can influence the separation performance of membranes.

Evonik is also working on innovative polymer membranes for water electrolysis that can help make green H_2 more affordable. Green H_2, which is critical for use as a carbon-free fuel for industry and transportation and as a raw material for the chemical industry, is produced from water by electrolysis using electricity generated from renewable resources. It is still much more expensive than conventional H_2, which is generally obtained from steam-methane reforming, a process that releases CO_2. In addition to sufficient low-cost energy generated from renewables, investment in an electrolyzer is a key factor in cost-efficient

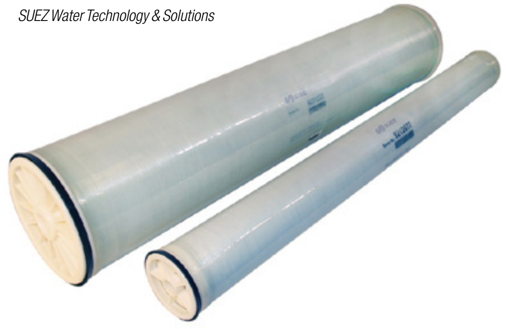


FIGURE 3. SUEZ is developing spiral-wound elements that are more resistant to high temperatures, pH levels and higher pressures

production of green H_2.

Evonik has developed a new anion-exchange membrane (AEM), which should contribute to the breakthrough of electrolytic production of H_2. "Electrolysis featuring anion-exchange membranes has benefits over other electrolytic processes such as conventional alkaline electrolysis using diaphragms (AEL) or the more recent method of proton exchange membrane electrolysis (PEM), which is dependent on raw materials such as precious metals. "Because the anion-conducting membranes work in a caustic versus acidic environment, standard 316 stainless steel can be used in the electrolyzer," says Baumgarten. "In PEM electrolyzers, precious metal-plated and rare-earth metals are needed, the expense of which could limit the future of a H_2 economy. This development featuring our anion conducting membrane systems will be launched next year and move us closer to a H_2 economy."

Likewise, the trend toward sustainability regarding water conservation and reuse is driving the need for membranes that can withstand higher temperatures and pressures. "As chemical and other processors try to conserve water, they are wanting to reuse water that traditionally would have been sent to treatment facilities," says Erik Hanson, director of global product management and strategy, with SUEZ Water Technology & Solutions (Trevose, Pa.; www.suezwatertechnologies.com). "Traditionally reverse osmosis (RO) and nanofiltration (NF) have been used for many years for treating water coming into plants and existing membranes worked well for those applications. But when you are using water that has gone through one or more industrial processes, it has things in it that are perhaps less predictable than what you find in intake water, so in reuse and zero-liquid-discharge (ZLD) applications, we are seeing more innovation in membrane technologies to enable these separation processes.

"This type of water might have more extreme pH or the temperature might be higher than what you would start with in a typical RO treatment, so today's parameters are taking us beyond what the RO elements of a decade ago would be able to handle," continues Hanson. "There is a lot of innovation for spiral-wound elements that are making them more resistant to high temperatures, pH levels and higher pressures" (Figure 3).

For example, as salt concentrations get higher and processors need to operate at higher pressures to recover those salts, SUEZ's Industrial RO 5, RO 6 and RO 7 elements can be used. "These elements are made with special membranes and special element construction to provide high rejection of salt at higher-than-average brine concentrations and pressures," says Hanson.

In other cases, industrial processes may make water acidic. Purifying or concentrating those acids requires a membrane element that can be continuously operated at low pH. "Our Duracid membrane element can continually operate in the 2 to 3 pH range, helping processors reuse water without having to do a lot of pH adjustment prior to treatment," Hanson continues. "If you didn't have an element like this and you wanted to purify an acid stream to enable water reuse, you would first have to neutralize it, which means adding a lot of caustic at a significant expense. The development of a membrane that can operate at low pH avoids that neutralization, saving time and expense."

Overcoming fouling

Since fouling and scaling have long been a major challenge with membranes, several manufacturers are working on improvements that will help processors reduce their environmental footprint and often enable the use of membranes in applications where it may not have been previously possible.

"Fouling is one of the most common and severe problems in the operation of RO systems. Unchecked, it causes significant operational problems such as frequent interruption, damage to the membranes, intense chemical and energy use and regular cleaning-in-place of the RO and the pressure exchangers," says Tina Arrowood, principal research scientist with DuPont Water Solutions (Edina, Minn.; www.dupontwatersolutions.com). "The bottom line is far less water produced for the money operators spend on capital assets and operations."

The company is currently produc-

FIGURE 4. The Aqua Membranes product features a customized 3D-printed pattern on the membrane to reduce fouling and wasted pressure

FIGURE 5 Using Vibratory Shear Enhanced Processing (VSEP), New Logic developed a fouling-resistant membrane filtration system that vibrates the membrane using resonance, which creates high shear at the membrane surface, improving fouling resistance by preventing congregation of the salts at the membrane surface

FIGURE 6. Toray achieved performance improvement by precisely controlling the size of micro pores, such as molecular gaps in RO membranes, and by improving the structure of the folds on the surface of separation membranes with its TBW-HR series of ultralow-pressure RO membrane elements

FIGURE 7. DuPont's FilmTec Prime RO membranes for the treatment of brackish water in industrial applications require up to 20% less energy while improving permeate quality by up to 60%

ing its fourth-generation fouling-resistant membrane technology, which reduces the need for cleaning by as much as 50% for wastewater reuse applications for industries including petrochemical, coal-to-chemical, paper and pulp, microelectronics and textiles.

Kurita is also working to reduce fouling in cooling-tower water treatment, helping reduce water use and expenses, via its Cooling Tower Blow Down Recovery System (CTBR). The technology recovers a higher rate of tower blowdown water, conditioning it and returning it to the cooling tower system, minimizing the operating costs of acquiring fresh water and discharging blowdown as wastewater. The approach combines chemicals, equipment and service. While many other systems face continued fouling issues of the filter media and membranes, decreasing the total recovery rate of the system and increasing water use, Kurita's CTBR solution effectively removes suspended solids in cooling water, inhibiting fouling, decreasing water use and maximizing the recovery rate of tower blowdown for a more reliable operation.

Also interested in reducing fouling and striving for energy conservation, Aqua Membranes (Albuquerque, N.M.; www.aquamembranes.com) has developed a new manufacturing method for the production of RO and UF membrane elements. "Membranes require frequent cleaning due to their construction," says CEO Craig Beckman. "The layers separating the membrane where fluid flows are separated by a net material constructed of extruded polypropylene. While that net creates turbulence in the membrane that is designed for the feed flow to come through, it is also the part that scales after separation has taken place, necessitating cleaning. What many people don't realize is that the energy associated with cleaning the membrane is a significant percentage of the energy required to run it."

He continues to say that Aqua Membranes constructed a membrane element using printed spacer technology that does not include the netting element, reducing fouling and pressure drop, thus providing energy savings. The Aqua Membranes product features a customized 3D-printed pattern on the membrane to reduce fouling and wasted pressure (Figure 4). "We use flat sheet membrane purchased from a supplier as our printing substrate and run it through our patented printing process. We end up with brail-like dot and line patterns on the membrane surface. This pattern covers only 2 to 3% of the membrane, but it's enough to create the flow channels and customize the flow through the system, resisting fouling and providing energy savings because less cleaning is needed," he says.

Dynamic membrane systems that reduce fouling can also be an enabling technology for many applications, says Greg Johnson, CEO and co-founder of New Logic Research (Minden, Nev.; www.vsep.com). "Conventional spiral-wound membranes have a very tight space between the membranes and use high laminar cross flow to pump liquid through a filter at a high rate of speed to create shear at the membrane surface. But as the membrane allows water to pass, the solids are left behind and congregate at the membrane surface, causing scaling and fouling. This is known as concentration polarization," Johnson explains. "Using our Vibratory Shear Enhanced Processing (VSEP), we developed a fouling-resistant membrane filtration system that vibrates the membrane using resonance, which creates high shear at the membrane surface, improving fouling resistance by preventing congregation of the salts at the membrane surface" (Figure 5).

This unique method has allowed the use of membrane systems in many viscous or other applications where it may not have been possible to use membranes or other separation technologies in a cost-effective way, notes Johnson. "Often in challenging separations, our equipment is the enabling technology that can allow separations or purification that would not otherwise be possible," he says. "While some of our applications are in the chemical processing or purification industry or the industrial wastewater industry, we have a lot of projects installed treating biogas effluent. In these applications, processors take organic material like manure or food waste and digest that in an anaerobic digester where methane is extracted and sold as a gas, but they are left with effluent that must be treated and our membranes can help with that. We also treat leachate from landfills and help other companies achieve zero- or minimal-liquid discharge."

Increased selectivity

"One of the biggest challenges in membrane-separation technology is to break through the trade-off

between rejection (selectivity) and permeability. In other words, achieving a process that enables the required water quality to be obtained with lower energy consumption and cost," says Tatsuya Tamura, general manager of the water treatment division, RO membrane products department, with Toray Industries (Tokyo, Japan; www.toray.com). "The performance of water treatment membranes depends on the separation target-size sieve, the membrane surface charge and the interaction with the substance to be separated."

One recent development is the improved performance of membranes for the removal of both small neutral molecules and ionic substances, such as dissolved organic matter and silica while maintaining water permeability. Toray has achieved this performance improvement by precisely controlling the size of micropores, such as molecular gaps in RO membranes and by improving the structure of the folds on the surface of separation membranes with its TBW-HR series of ultra-low-pressure RO membrane elements. Impurity rejection with these membranes exceeds that of existing ultra-low pressure RO membrane elements (Figure 6).

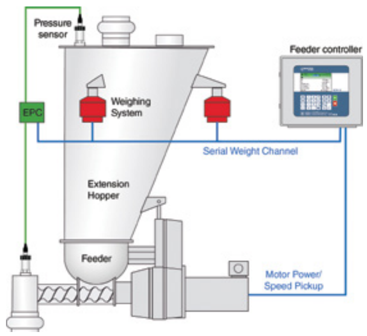
As demand for purer water has risen in the electronics industry, a key prospective benefit of these new membranes is purification of higher-quality and higher-purity water, enabling the production of semiconductors with finer wires as increasingly compact and complex semiconductors are needed for new applications.

In addition to meeting a demand for new applications, innovations in RO element selectivity are also helping with sustainability efforts. DuPont recently launched a new portfolio of RO elements, FilmTec Prime RO, for the treatment of brackish water in industrial applications (Figure 7). These elements require up to 20% less energy while improving permeate quality by up to 60%. "Analysis using U.S. Environmental Protection Agency tools indicates that the positive sustainability impact of FilmTec Prime RO, which has the potential to reduce global CO_2 emissions by approximately 85,000 metric tons each year (based on global adoption), is equivalent to the emissions generated by an average car driving 211 million miles," says DuPont's Arrowood. "This global sustainability impact is delivered while retaining compatibility with existing brackish-water RO treatment systems, allowing operators to upgrade easily and secure the benefits of the technology," she continues.

"As water conservation and reuse and other sustainability-based applications continue to grow, flexibility and new features in membrane technologies, as well as the ability to tailor membranes to remove a specific contaminant or operate under unusual pressures or temperatures, will enable us to push them harder to meet the needs of processors. These advancements will be key for those looking to improve their water or energy footprint," says Kurita's Galligan. ■

Joy LePree

Weighing and Dosing



Coperion K-Tron

Automated Flexible Conveyor

Grundfos

Readco_Kurimoto

Pressure compensation ups accuracy in LIW feeders

Loss-in-weight (LIW) feeder performance is dependent on accurate weighing, which can be affected by a variety of influences. In a closed system, pressure variations, such as backpressure from a downstream mixer or extruder or air pressure in the hopper due to a clogged filter, can affect the weight reading of the scale and therefore feeding accuracy. Electronic Pressure Compensation (EPC; photo) is a simple yet effective alternative to traditional mechanical pressure compensation. EPC has been shown to significantly improve feeding accuracy of gravimetric feeders in closed systems and can be less expensive than traditional solutions. In addition, the electronic solution is more effective and reliable, maintenance free and easy to retrofit on existing systems. — *Coperion K-Tron (Switzerland) LLC, Niederlenz, Switzerland*
www.coperion.com

A mobile batch-weighing system rolls to where needed

Offered as an option, the mobile Batch-Weigh system (photo) was developed to enable powder processors to safely and easily roll the screw conveying system from one tank, vessel, mixer, hopper or other location to another, or from one processing line to another, without investing in multiple powder-conveying systems. The conveyor can be used to automatically transfer, weigh and dispense precise amounts of powders, pellets, flakes and other bulk materials and then be quickly cleaned and rolled to the next location. — *Automated Flexible Conveyor, Inc., Clifton, N.J.*
www.afcspiralfeeder.com

A dosing pump with many digital features

The DDE pump (photo) offers a cost-effective Digital Dosing solution with basic functions for simple applications and covers a wide flow range of up to 52 gal/h and up to 145 psi. Setting dosing capacity from 0.1 to 100% is easy on the intuitive user interface. The PR and P control variants offer pulse control and inputs for external stop, low level and empty tank signals. The PR control variant also offers relay setting of alarm, warning, stroke signal and pump dosing, as well as two output relays. The larger DDE XL AR is available in flow range over 15 gal/h and allows analog input control in addition to the PR features. — *Grundfos Americas Corp., Lenexa, Kan*.
www.grundfos.us

Continuous processors permit lot traceability

Continuous Processors (photo) enable food, nutrition, chemical, pharmaceutical and other manufacturers to track and trace lots in a continuous-processing environment. Devised to support compliance with the FDA Food Safety Modernization Act (FSMA), the Continuous Processors can establish a positive cutoff for lot traceability from nearly any desired point based on volume, weight, time, shift, raw material lot or other criteria. The processors mix, blend, react, compound, crystallize, encapsulate, and perform other processes with multiple liquid, dry and viscous materials in a single step. The result at discharge meets specifications for moisture, texture, color, uniformity and other properties as targeted. — *Readco Kurimoto, LLC, York, Pa.*
www.readco.com

Robotic sample preparation increases productivity

Automation and robotics relieve scientists of tedious, time-consuming and repetitive work while enhancing speed, improving accuracy and enabling faster product development. Chronect XPR robotic powder-dispensing can ease bottlenecks in screening preparation and open new perspectives in high-throughput experimentation. Automated weighing with Chronect XPR provides ultra-accurate, safe and reliable robotic powder dispensing. With such an unattended, automated screening preparation that runs overnight, users can simply continue with the reactions in the morning, thus eliminating this tedious step in their experimentation.

Blue White Industries

Flexicon

Schenck Process

Best Process Solutions

Gericke USA

Laboratory automation can reduce process errors by 50% and increase productivity by up to 75%, says the company. — *Mettler-Toledo GmbH, Greifensee, Switzerland*
www.mt.com

Dose harsh chemicals with this maintenance-free pump

The Chem-Feed CD1 multi-diaphragm pump (photo) is engineered to ensure almost no maintenance. The patented single-layer DiaFlex diaphragm has been designed to last the life of the pump. The pump can be used for dosing with gas-forming chemicals, such as peracetic acid or sodium hypochlorite. The pump is self-priming, will not vapor lock and is easy to install and operate. The pump delivers a dosing rate of up to 7.70 gal/h (29.2 L/h) of harsh chemicals. — *Blue-White Industries Ltd., Huntington Beach, Calif.*
www.blue-white.com

This batch system has an integral conveyor

The automated Bulk Bag Weigh Batching System (photo) meters ingredients into a Flexi-Disc Tubular Cable Conveyor that transports batches of a specified weight to downstream processing equipment, dust-free. The Bulk-Out BFC Series bulk-bag discharger features a cantilevered I-beam with electric hoist and trolley for loading and unloading of bulk bags without the use of a forklift. Flow-Flexfeeder bag activators raise and lower opposite bottom edges of the bag at timed intervals, promoting continuous and complete discharge of free- and non-free-flowing materials through the bag spout. The discharger rests on load cells that signal a programmable logic controller (PLC) to stop a vibratory feeder that meters material into the conveyor once a preprogrammed batch weight has been metered out. — *Flexicon Corp., Bethlehem, Pa.*
www.flexicon.com

Versatile feeder handles a wide range of bulk solids

The MechaTron dry material feeder (photo) can handle a wide range of volumetric or gravimetric feeding applications for bulk solid materials, such as TiO_2, talc and carbon black. Feed rates from 0.002 to 1,100 ft^3/h can be achieved with the MechaTron. Complete disassembly from the non-process side of the feeder eliminates the need to remove upper extension hoppers, bins, bulk bags and intermediate bulk containers (IBCs) to clean or maintain the feeder. Flexible or all-stainless-steel hoppers are available to accommodate any unique dry material feeding application. — *Schenck Process LLC, Whitewater, Wis.*
www.schenckprocess.com

Twin-screw feeder delivers precise batch weight

The Model TSF twin-screw feeder (photo) is designed for precise batching and weighing applications. The feeder's dual-helix design combines fast, high-volume filling with accurate dribble flow at the end of the cycle. Its compact design is ideal when limited space prohibits multiple individual screw units. Two helixes (1.5- and 4-in. dia.) are mounted on a hopper and deliver 17 and 283 ft^3/h feedrates, respectively, at maximum speed with 100%-efficient conveyable product and no slippage. TSF is ideal for batching to weigh-hoppers; low loss-in-weight scale-monitored flow; low loss-of-weight batch applications with scales; drum and pail packout lines; and recipe-type batching by multiple computer-controlled units. — *Best Process Solutions, Inc., Brunswick, Ohio*
www.bpsvibes.com

Sleeves weightlessly connect weighing equipment

Developed as a hygienic method for linking processes in food, pharmaceutical, nutrition, chemical and other sanitary processes, the GFT Sleeves (photo) replace cumbersome clamps and polyester and textile sleeves that can trap materials in process with a design that sets the sleeves between two mounting rings to form air-tight, waterproof connections. They are made from food-grade vinyl methyl silicone (VMQ), and disassemble easily for quick cleaning. The line of sleeves comprises five sizes in diameters, ranging from DN 65 to DN 200 mm (2.5 to 8 in.). — *Gericke USA, Inc., Somerset, N.J.*
www.gerickegroup.com ■

Gerald Ondrey

New Products

Use these diffusers to prevent settling in sewage-storage tanks

ProFlex 730CBD coarse-bubble diffusers (photo) are used to aerate or mix wastewater for effluent and sewage treatment, ensuring proper agitation of media with high specific gravity. This means that when the sewage is put into a storage tank, settling at the bottom of the tank will not occur. The ProFlex 730CBD is an engineered molded valve, which, when submerged and charged with air, will create a series of bubbles strong enough to capture the sewage effluent and carry it to the surface of the tank. Featuring an elastomeric duck-bill design, the valve is always in a 100% closed position and relies on static head to open. Thus, the instant there is an absence of inlet pressure, the valve is closed bubble-tight, ensuring that unwanted media does not flow back into the manifold. — *Proco Products, Inc., Stockton, Calif.*

www.procoproducts.com

Proco Products, Inc.

Heavy-duty mixers for very viscous materials

Heavy-duty FGM-series mixers (photo) feature a high-torque gear reducer to vigorously agitate heavy viscous materials. With a ring-mount design and two opposing handles, this powerful mixer mounts directly to 5-gal pails up to 12.25-in. wide. A quick-change coupler and shaft design incorporate a shaft pin that locks in place during rotation. Three 9-in., two-blade propellers made from 319 aluminum attach to the 15-in. long shaft with set screws. Powered by a 1-hp totally enclosed, fan-cooled motor that is ready to plug into a standard outlet, the FGM-1T electric mixer operates at a fixed speed of 350 rpm. Additional motor options include fractional horsepower fixed and variable-speed electric versions, as well variable-speed air-powered models. Additional impeller options are also available. The FGM-series mixers are appropriate for mixing viscous materials, such as adhesives and sealants, as well as viscous primers, paints and other commercial coatings. — *Indco, New Albany, Ind.*

www.indco.com

Indco

Stackable drum racks and sumps prevent chemical spills

This company's pallet-rack spill-containment sumps (photo) catch spills and drips associated with liquid storage and dispensing, keeping areas neat and safe. Containment sumps positioned beneath the drum rack are manufactured of heavy-gauge steel, which is galvanized for long service life with a rust-free appearance. They feature fully welded frame construction for durability, with sump welds fully inspected with low-viscous test fluids to ensure leak-tightness. A forklift pocket allows sumps to be moved easily. Sumps are sized to meet or exceed OSHA, EPA, NFPA, UFC and other requirements. Galvanized steel grating provides secure platform for vertical drums. Sump liners are available for highly corrosive liquids. Versatile designs and configurations allow the vertical or horizontal storage of drums, pails and small containers, as well as IBC totes. — *Denios Inc., Louisville, Ky.*

www.denios-us.com

Denios

This pressure-relief valve enables in-field adjustability

The Model L11F weight-loaded pressure-relief valve (photo) is designed to be used on tanks, piping and low-pressure vessels, and can be used as a standalone unit or in addition to existing pressure-relief valves to add additional flow capacity. It also includes a calibrated weight system that gives the operator the flexibility to adjust the set pressure of this valve on the top of the tank, eliminating the need to remove and retest in the shop on a test stand. According to the manufacturer, users can easily maintain, adjust settings and replace the L11F in the field, reducing downtime and lowering operational cost. Furthermore, the product runs at a wide range of flowrates. Made with aluminum casting, stainless-steel seats, polyphenylene sulfide (PPS) pallets and zinc-coated carbon-steel weights, the L11F comes in sizes from 2 to 6 in. (50 to 150 mm) and is available with leakage rates compliant with API 2000 requirements. — *LaMot Valve & Arrestor, Stafford, Tex.*

www.lamotvalvearrestor.com

LaMot Valve & Arrestor

Franklin Electric

Atlas Copco Compressors

Aquajet Systems

Trelleborg Sealing Solutions

This modular system streamlines pump and motor configuration

Pioneer Pump ElectricPAK (photo) is a modular, electric pump package that helps users receive a pump-and-motor configuration onsite more quickly and efficiently than custom-built units. Each configured assembly includes a high-performance pump and electric motor that can provide high heads and efficiency. The unit also features a rigid motor stool that keeps the pump and motor permanently aligned. This feature eliminates the need for time-consuming alignment work or special tools upon delivery or when the unit is moved. The ElectricPAK's modular system, combined with an extensive range of motor choices, allows users to select the most efficient pump based on the duty point. Users can also choose from a stationary base or drag skid. Helping them make their selection is this company's proprietary FE Select online specification tool. — *Franklin Electric Co., Fort Wayne, Ind.*
www.franklin-electric.com

New midsize models and features added in this PSA range

The NGP+ series of pressure-swing-adsorption (PSA) nitrogen generators (photo) is expanding with the introduction of two new models — the NGP 160+ and NGP 200+. The generators offer gas purity from 95% to 99.9995%, with flowrates up to 4,802 std. ft^3/min. The midsize NGP+ models feature the Elektronikon Touch controller, which enables easy gas-purity selection and advanced connectivity options. This controller optimizes performance and continuously measures gas purity. It also monitors the feed air to safeguard the integrity of the adsorbent. Other newly available options include a room oxygen alarm and the ability to produce ultra-dry nitrogen. — *Atlas Copco Compressors LLC, Rock Hill, S.C.*
www.atlascopco.com/air-usa

A robotic unit to expedite industrial cleaning

This company's Ergo System (photo) is a compact hydrodemolition robot used for hazardous cleaning applications, such as those requiring the removal of concrete, coatings, paint, rust, plastic or other materials. The Ergo offers four times the power of a hand lance and provides maneuverability through remote operation to keep workers safer, says the company. Using a number of attachments, the Ergo System can be operated remotely for efficient cleaning and removal of material in boilers, tanks, pipes and other industrial containers and conduits. The Ergo System incorporates a controller unit, which powers and controls the hydraulics, the Ergo power head, which manipulates the high-pressure lance, and either a spine or a climber, which are unique systems used to support and maneuver the power head, based on project needs. The climber attaches to any standard scaffolding or pipes and robotically moves along it to remove material. — *Aquajet Systems AB, Holsbybrunn, Sweden*
www.aquajet.se

Accelerate product development and small-batch production

A new flexible digital-manufacturing process for product development and small-batch production of liquid silicone rubber (LSR) parts — iCast LSR (photo) — enables manufacturers to develop product variations or try out different design concepts before investing in serial production tools. In addition, the process enables the start of pre-series and series production with small batches, to close the gap between low- and high-volume production. It is an adaptable five-step modular process that utilizes digitization and new manufacturing techniques to dramatically decrease the time required to produce prototypes, says the company. The process starts with the submission of 3D part data and order details. A feasibility study based on artificial intelligence (AI) is triggered to confirm if the iCast LSR process is suitable for production of the part. Upon completion of the feasibility study, the part design is analyzed, and the individual digital-mold layout is created based on 3D data. In a virtual environment, this process identifies the optimum production process for the use of additive manufacturing (AM) technologies in order to achieve the best possible quality. — *Trelleborg Sealing Solutions AB, Stockholm, Sweden*
www.trelleborg.com/seals ■

Mary Page Bailey

Clean-in-Place (CIP) Systems

Department Editor: Scott Jenkins

Cleaning equipment surfaces is critical for processes involving biological materials to prevent microbial contamination. Clean-in-place (CIP) systems play a key role. In addition to preventing contamination, CIP systems also remove grit, scale and organic matter, which may affect process performance. This one-page reference provides information on CIP system equipment and operating considerations for bioprocessing facilities.

CIP equipment

CIP systems supply fluid to a spray device inside the vessel, which sprays the solution onto the vessel walls. A variety of spray devices are available, including static sprayballs and fluid-driven orbital cleaners. Sprayballs are high-flow, low-pressure devices often used to clean tanks smaller than 15-ft dia., while fluid-driven orbital cleaners are low-flow, high-pressure devices used for tanks greater than 15-ft dia.

Tanks. Tanks are typically constructed from 304L or 316L stainless steel. Internal welds should be ground smooth and dead spots should be minimized. Internal polishing of CIP vessels is usually not required. Detergent tanks should be equipped with agitators to ease the preparation of detergent solutions.

Pumps. There will likely be multiple unit operations and tanks using the same CIP solutions, but with different flow and pressure requirements. To address this situation, variable-speed drives (VSDs) or parallel pumps (systems with different flows and heads) may be used to meet the range of requirements. Pumps are normally centrifugal, often with VSDs. Net positive suction head (NPSH) requirements are an important consideration, due to the elevated temperatures required for some CIP fluids. Hydraulic losses for spray nozzles and equipment (heat exchangers, sterilizers and more) need to be calculated based on vendor information.

Piping. Key considerations of piping design for CIP systems include the proper design of CIP circuits, the ability to drain CIP lines, and the appropriate segregation of the CIP system from the process being cleaned. Ideally, dead legs should be no longer than two pipe diameters, and the overall system should be designed to drain completely. Lines should be sized for fully turbulent flow. The general practice is to have a velocity range of 5 to 7 ft/s. All horizontal lines should be sloped to a drain point, and low points must be equipped with drains. The minimum slope of the pipe should be at least 1/16 in. per ft. Valve selection should avoid non-drainable conditions or crevices that will not be cleaned. So-called "clean" ball valve designs are available for sizes 6 in. and less. For larger sizes, hygienic butterfly-valve designs should be considered. The tie-in point between the CIP system and the process should be either a block-and-bleed connection, or a line break.

Instrumentation. Generally recommended instrumentation for CIP processes includes the following:

- Visual sightglasses for CIP supply and return lines
- Temperature indicators on the caustic, acid and rinse-water tanks
- Conductivity transmitters in the CIP supply and return lines
- Temperature indication and control on the cleaning solution heater
- Temperature indication in the CIP return line
- Level indicators on all tanks
- Differential pressure indicators across filters and heat exchangers
- Limit switches confirming position of crucial valves

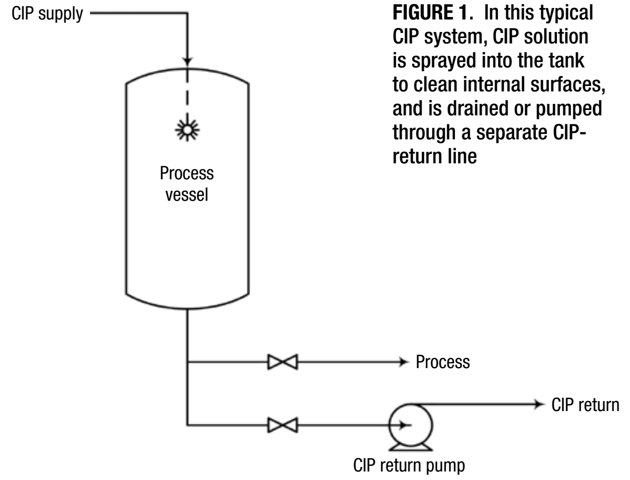


FIGURE 1. In this typical CIP system, CIP solution is sprayed into the tank to clean internal surfaces, and is drained or pumped through a separate CIP-return line

CIP operation

A typical CIP sequence includes the following elements:

Process heel drain. A complete drain of the heel is needed to minimize waste and avoid contamination of the cleaning fluid.

Pre-rinse. The primary objective of the initial rinse is the mechanical removal of dirt. Water recovered from a later step in the CIP sequence is used for the pre-rinse step. The pre-rinse effluent stream may need to undergo a bio-deactivation process before being sent for further waste treatment.

Detergent wash. This step involves chemical cleaning to remove remaining dirt. The detergent solution is circulated through the system. The solution type and concentration should be determined by plant experience. While a 2–4 wt.% caustic solution is commonly used in this step, an acid-based detergent (or both) can also be used, depending on the type of dirt or other contaminants present.

Water rinse. A once-through rinse of clean water is typically used, with no circulation. This substantially reduces the amount of residual materials from the detergent wash step. If no acid wash is used, this water rinse step becomes the final rinse prior to either sanitization or sterilization. The rinse water should be collected for reuse as the pre-rinse fluid used in the next CIP cycle.

Acid wash. The solution used in this step may be circulated in a loop (similar to the detergent wash). This step serves two functions: to neutralize and remove any remaining caustic from the detergent wash step; and to remove any hard-water-scale deposits that may occur within the process equipment. ■

Editor's note: The content for this column was adapted from Miley, B., Riley, J. and Zelmanovich, Y. Large-Scale Fermentation Systems: Hygienic Design Principles, *Chem. Eng.*, Nov. 2015. pp. 59–65.

Can Trash Interfere With a Cure?

Henry Kister shares lessons learned from troubleshooting distillation towers

Construction of new production units has an undesirable byproduct: trash. Sometimes the hard question is — Who will clean? The author was the startup superintendent on a new unit in an olefins plant in Australia that produced polymer-grade propylene. Terry was the foreman working for him and Stan was the project engineer taking care of mechanical issues. Terry worked closely with the shift team, but they directly reported to their shift foreman.

At this point in the startup, the auxiliary units were commissioned, operating and tested. Everyone was preparing for the exciting moment of hydrocarbon introduction that was scheduled for Friday night, with production of on-specification polymer-grade propylene by Monday morning. For months, everyone had been working tirelessly to meet the target startup date. The climax drew near, right on schedule.

Early that week, an inspection by the production manager found unlevel ground, wide patches of dirt, missing pavement, piles of sand and rocks, chunks of metal, debris and trash. "Get Engineering to have these improved before we start," he instructed us. The engineering project manager replied, "This work is outside of our scope. If Production requires these improvements, they can do them themselves."

In response, and regarding this as a safety issue, Production put a "hold" on the startup until the improvements were made by Engineering. But Engineering stayed defiant and a stalemate resulted. After months of working day and night to meet the tight schedule, the scheduled startup was threatened because the players could not come to agreement on who should clear the ground. A cloud of gloom came over the team's faces, replacing the enthusiasm of engineers and operators.

Suddenly, early Friday morning, bulldozers, earth-moving equipment, and large crews arrived and diligently started leveling the ground, clearing it, paving it, and removing the trash and debris. Our team breathed a sigh of relief.

Mid-morning, a call came from the production manager. "Please thank Engineering for coming good at the right time." The engineering manager was out, but an hour later he stopped by our trailer, face shining and said, "Please thank the production manager for clearing the ground. We are so glad that the startup will not be delayed."

"He is thanking you for this. It was not you?" we asked. "No, he replied. I thought it was the production manager."

This made no sense. Stan, the engineering manager and I walked up to the work crews, asked their supervisors, but they had no idea who ordered the work. Terry was not around, and was presumably with the operators. We returned to the trailer empty-handed.

By about 3:00 p.m. the ground was level and clear. The trash had been removed, everything looked beautiful and the bulldozers and earth-moving equipment were heading out of the gate. Terry walked into the trailer. "G'day Terry. Any idea who ordered this earthwork?" A big grin appeared on Terry's face. "You?" Stan and I yelled out.

"For months the operation teams were working [hard] to beat the deadline. Management was telling them that delays cost $200,000 a day (1970s dollars). Operators and foremen as well as we worked extra hours, sometimes with no extra pay, and kept on schedule. And after this, Production and Engineering act as if this deadline means nothing and are making a joke out of the whole crew. How would you feel if you were part of the crew?"

Stan and I looked at each other, then at Terry. "Terry, you are our hero. We endorse your action and will take responsibility. Thanks for saving the startup." Then we added "That is why you made yourself scarce until now." Another grin on Terry's face. "Thanks for your support."

An hour later the crews were done. We contacted Engineering and Production and told them what happened. With the startup being so close, the production manager was

FIGURE 1. This is a front view of the propylene purification column

glad that it was proceeding and decided to go easy on us. "We'll discuss it further on Monday." The engineering manager was supportive. "I used to work in a plant and know where you are coming from. Let me talk to some people next week, maybe I can sway them to chip in to some of the costs."

The startup went ahead. Polymer-grade propylene was produced by mid-day Sunday thanks to a very enthusiastic operations team gleaming at Terry's success to avert the stalemate. This was 18 hours ahead of schedule, saving $150,000 — more than the cleanup costs.

Word of the startup success spread fast. Monday morning, a team of engineering top management flew in from Melbourne to get first-hand sight of the wonder. After they left, the engineering manager stopped by.

"Did you already tell the production manager that it was not us that ordered the cleanup?"

"Sure, we told both him and you last Friday."

"Can you tell him that this was a mistake and that it was indeed us that cleaned up? And please make sure that all the bills are forwarded to us. We will pay."

"I am sure he will be glad to hear.

But all this makes no sense. Last week you would not pay a penny. What the [heck] is going on?"

"Do you really want to know?" "Sure."

"Our president walked through the plant this morning. He was so impressed with how tidy and clean the site looked, and said he never saw such a clean new plant in his life. He congratulated all of us for making it happen. We did not have the heart to tell him the real story. But we sure owe Terry one"

Terry grinned one more time "Don't worry about it. Glad it is all settled. You can buy me a steak and a drink for lunch next Friday."

The takeaway: A doctor's work is supported by staff. Always appreciate their effort, especially during stressful times. ■

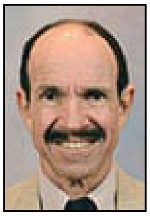
Edited by Dorothy Lozowski

About the Tower Doctor

"The Tower Doctor" is the honorary title bestowed upon the author of this article in 2002 by Richard Darton, professor of Engineering in Oxford University and chair of the European Distillation Network. "When a tower is not well," says Darton, "people call Henry to diagnose the illness and find a remedy. He arrives with his doctor's bag, examines the patient-tower, measures its temperature and pulse, gets radiography to get an inside look. Then comes his diagnosis and cure. Towers treated by Henry mostly get better very quickly."

Being son to two medical doctors who were blessed with phenomenal diagnosis ability, the author aspired to live up to this special honorary title. Like with medical doctors, some illnesses were a struggle to diagnose, others were easier. All were exciting. This column will reminisce through some of the more entertaining cases. They may not have seemed entertaining at the time, but looking back at them, they leave unforgettable memories and raise a smile or two. One great aspect of being a tower doctor, one gets to work with and learn from some of the greatest engineers and operators that contributed so much to the chemical industry. We hope that this column can pass some of the fun, excitement and lessons learned to future troubleshooters and tower doctors.

Author



Henry Z. Kister is a senior fellow and the director of fractionation technology at Fluor Corp. (3 Polaris Way, Aliso Viejo, CA; Phone: 949-349-4679; Email: henrykister@fluor.com). He has over 35 years of experience in design, troubleshooting, revamping, field consulting, control and startup of fractionation processes and equipment. Kister is the author of three books, the distillation equipment chapter in Perry's Handbook, and over 130 articles, and has taught the IChemE-sponsored "Practical Distillation Technology" course more than 530 times in 26 countries. A recipient of several awards, Kister obtained his B.E. and M.E. degrees from the University of New South Wales in Australia. He is a member of the NAE, a Fellow of IChemE and AIChE, and serves on the FRI Technical Advisory and Design Practices Committees.

Improve Energy Efficiency Using Heat Pumps

Heat pumps are an efficient way to provide space and process heating. Information on their types, and how to assess their potential benefits is provided here

Sebastiano Giardinella
Illinois Sustainable Technology Center

IN BRIEF

- HEAT-PUMP BASICS
- HEAT-PUMP PERFORMANCE
- HEAT-PUMP CLASSIFICATION
- HEAT SOURCES
- OTHER CONFIGURATIONS
- OPERATING RANGES AND REFRIGERANTS
- HEAT-PUMP PROCESS DESIGN
- AN EXAMPLE CALCULATION
- CONCLUDING REMARKS

Approximately 40% of the energy that is used in buildings in the U.S. goes toward keeping indoor spaces comfortable. Heat pumps provide a proven, efficient way to provide this service.

Whereas a heater can only convert less than 100% of the energy put into the device into useful heat, a heat pump can provide many multiples of the device energy input by combining the heat rejected from said device with heat available from a typically free source. This translates into a much lower energy cost over the heat-pump lifecycle, which pays for its typically higher initial cost when compared with a heater.

Heat pump technology applications have been growing, from typical refrigeration, space heating/cooling, to industrial or hybrid uses in the chemical process industries (CPI).

This article discusses heat pumps, their types, working principle and components, and provides an overview of the process for defining, specifying and evaluating a heat pump project.

Heat pump basics

Heat pumps are devices or systems that extract heat from at least one source and transfer it to at least one sink at a higher temperature. A basic heat pump is based on the refrigeration cycle. Figure 1 illustrates the basic heat-pump steps over a generic pressure-enthalpy diagram:

Compression (1–2). Vapor is compressed to a higher pressure, P_{cond}, where condensation occurs.

Condensation (2–3). The vapor at a pressure of P_{cond} is condensed at the corresponding saturation temperature, T_{cond}, by transferring its heat to the sink, at a temperature of T_h.

Expansion (3–4). The liquid is expanded in a flow restrictor from the condenser pressure, P_{cond}, to the evaporator pressure, P_{evap}.

Evaporation (4–1). The liquid, at a pressure of P_{evap}, is evaporated at the corresponding saturation temperature, T_{evap}, by receiving heat from the source, at a temperature of T_c.

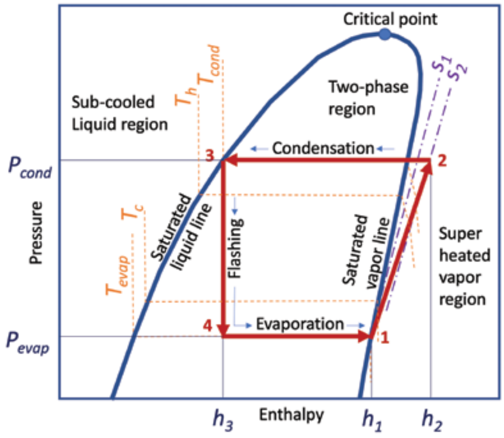


FIGURE 1. A pressure-enthalpy diagram for a basic refrigeration cycle is shown here

Both in the evaporator and in the condenser, there is a temperature difference with the surroundings to allow heat transfer to or from the working fluid. Hence, the evaporator works at a lower temperature than the source, and the condenser works at a higher temperature than the sink.

To compress the gas, additional energy needs to be supplied to the heat pump in the form of either power (typically electrical) or heat, depending on the type of heat pump as described below.

The total heat that is delivered to the high temperature sink is the sum of the heat being transferred from the low temperature source plus the work used in compression. The measure of the system performance depends on whether the heat pump is used for heating or cooling, as described below.

Heat pump performance

For heating service, the useful thermal energy that is delivered to the higher temperature sink is the total energy supplied to the heat pump resulting from the combination of heat taken from the lower-temperature source plus the energy used to drive the heat pump, minus the energy losses in the system, described by Equation (1):

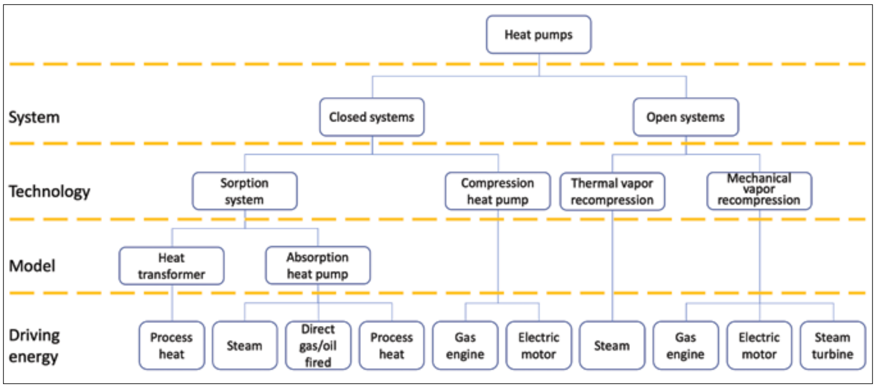


FIGURE 2. This diagram shows the classification of heat pumps (adapted from Ref. 2)

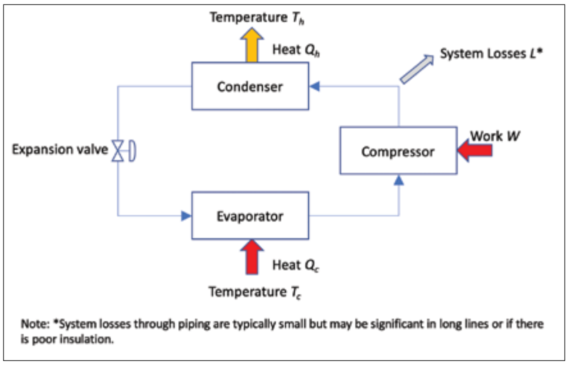


FIGURE 3. This diagram shows a mechanical (vapor-compression) heat pump

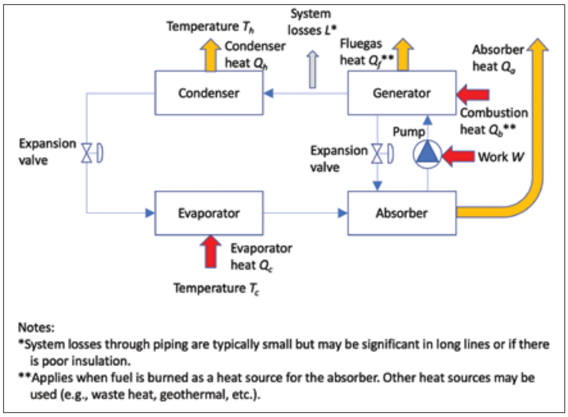


FIGURE 4. An adsorption heat pump is shown here

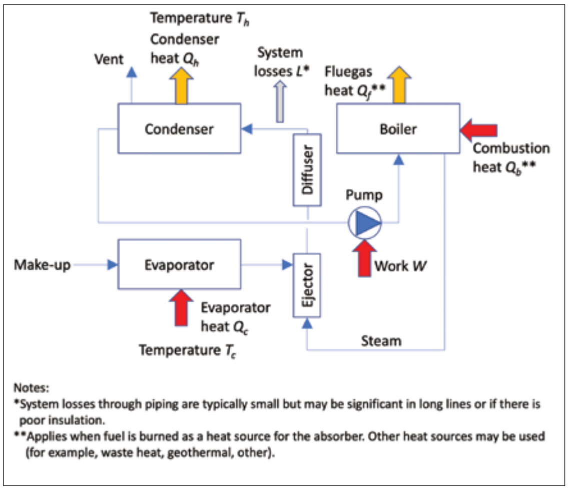


FIGURE 5. This heat pump features an ejector (steam-jet)

$$E_u = E_s + E_d - L \qquad (1)$$

Where:
E_u = Total useful thermal energy
E_s = Heat taken from low-temperature source
E_d = Energy used to drive the heat pump
L = energy losses in the system
(all values in consistent units)

The efficiency of the heat pump is measured by the ratio of useful thermal energy delivered, to the driving energy supplied to it. This ratio is known as the coefficient of performance (COP):

$$COP = E_u/E_d \qquad (2)$$

Equation (2) can be expressed in different forms depending on the type and configuration of the heat pump, as described further below.

Assuming a typical vapor compression heat-pump system, such as that shown on Figure 1, where heat, Q_c, is transferred from a source at a lower temperature, T_c, to a sink at a higher temperature, T_h, electrical power W is used to drive a compressor, and the net useful heat delivered to the sink is Q_h, the COP can be expressed as:

$$COP = Q_h/W \qquad (3)$$

Where:
Q_h = net heat delivered to high temperature sink
W = power supplied to the heat pump

The theoretical maximum coefficient of performance that can be achieved by the basic vapor compression cycle in Figure 1 is given by Equation (4):

$$COP < T_h/(T_h - T_c) \qquad (4)$$

Where:
T_c = Source temperature (absolute units)
T_h = Sink temperature (absolute units)

It is common for heat pumps to operate with COPs well below the theoretical maximum. There is continuous effort by heat pump manufacturers to design systems that are capable of reaching closer to the theoretical maximum COP.

For cooling service, the useful energy in Equation (2), E_u, can be expressed as the heat extracted from the low-temperature source. Assuming the same vapor compression cycle on Figure 1, the COP for cooling then becomes:

$$COP_{cooling} = Q_c/W \qquad (5)$$

The theoretical maximum cooling COP that can be achieved by the basic vapor compression cycle in Figure 1 is given by:

$$COP_{cooling} < T_c/(T_h - T_c) \qquad (6)$$

Heat-pump classification

Figure 2 presents a general classification chart for heat pump systems, segregated into system, technology, model and driving energy.

Based on system. Heat pumps can be classified into closed and open systems.

Closed systems have the working fluid confined within the boundaries of the system, with no material entering or exiting it.

Open systems, on the other hand, involve material exchange with the ex-

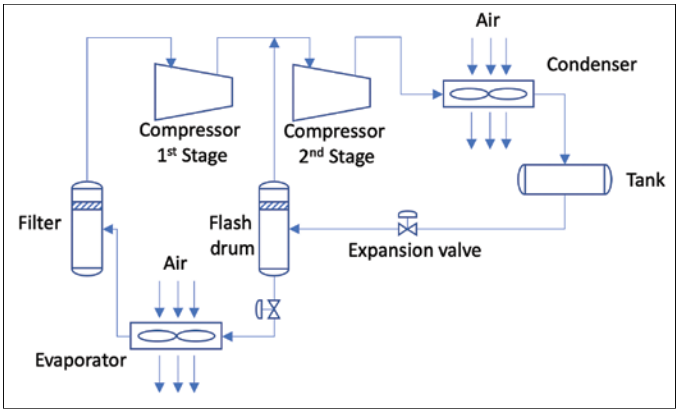


FIGURE 6a. An air-to-air heat pump with two compression stages is shown here

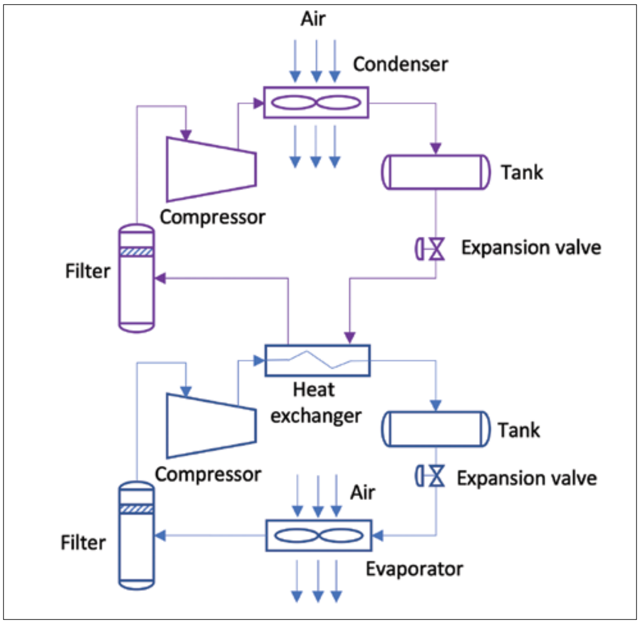


FIGURE 6b. Shown here is an air-to-air heat pump with two effects in series. A heat exchanger acts as a condenser for the low-temperature cycle and as an evaporator for the high-temperature cycle

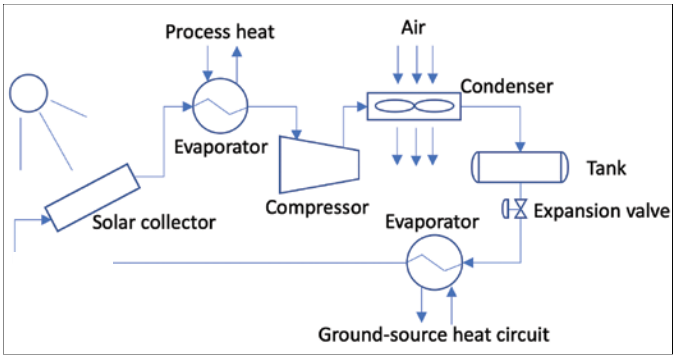


FIGURE 6c. This ground-to-air heat pump has solar and process heat boosts

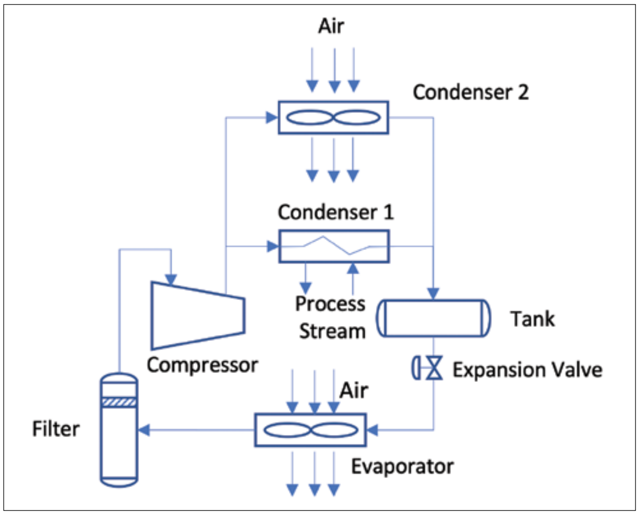


FIGURE 6d. In this heat pump, heat is transfered to a process stream and air in parallel

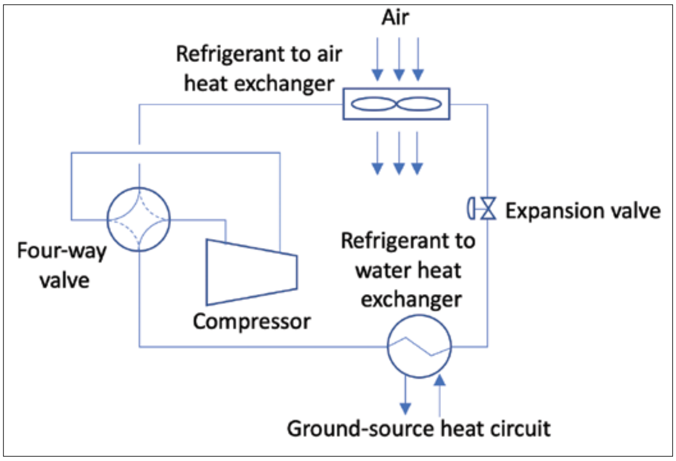


FIGURE 6e. Here, a reversible heat pump is shown that transfers heat from a ground source to air during winter and vise versa during summer

terior. The working fluid in these types of systems is used to transfer the heat, and a portion of it is taken from, and delivered to, the surroundings.

Based on technology. Closed systems are classified into compression or sorption-based systems, whereas open systems are of either thermal or mechanical vapor-recompression type. Figures 3, 4 and 5 show different basic configurations for each technology type.

Vapor-compression heat pumps, shown in Figure 3 (in this case, depicting an electrically driven compressor) use work to raise the pressure of the gas.

Sorption heat pumps, such as the absorption system shown on Figure 4, utilize a solvent with an absorption and desorption (generator) step. Depending on the sequence of the flow, the system may be classified as either an absorption heat pump or a heat transformer.

In an absorption heat pump, the solvent absorbs the gas from the evaporator, allowing the fluid to be pumped to elevate its pressure. The rich solvent is then subject to heat at the generator, which desorbs the gas at a higher pressure before the condenser. The lean solvent is returned to the absorber through a valve that reduces its pressure, and it is cooled to the initial absorption temperature.

Heat transformers operate on the same principle as absorption heat pumps, but in reverse: the condenser and generator operate at a low pressure, whereas the absorber and evaporator operate at a high pressure.

In comparison to vapor-compression heat pumps, sorption types utilize heat as the main driving en-

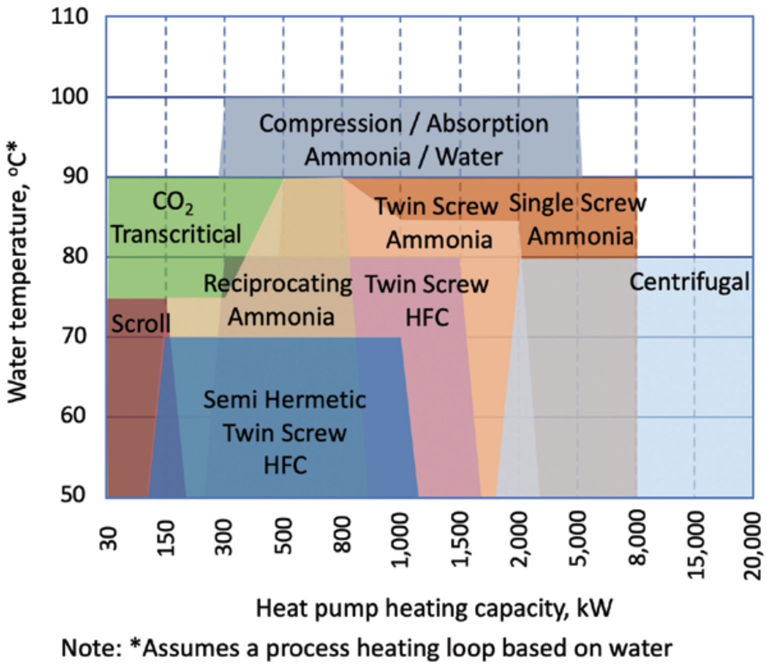


FIGURE 7. This chart shows the typical operating ranges for heat pumps (adapted from Ref. 2)

ergy, with a typically low consumption of electricity for pumping. Figure 4 shows combustion (for example, from natural gas) as a heat input to the system, but other suitable heat streams, such as waste heat, can be utilized. Also, depending on the configuration and integration with the surroundings, heat from the pump can be utilized for different temperature services: this includes heat from the evaporator, heat removed from the absorber, and heat losses (for example as fluegas) from the generator.

Figure 5 shows a thermal vapor-recompression (steam-jet) heat pump. This technology also uses a combination of thermal energy (in the boiler) and work (at the pump). In this case, the system is open as some of the steam is vented and make-up is added to the evaporator.

Mechanical vapor-recompression heat pumps differ from thermal vapor-recompression heat pumps in that they use a mechanical driver to move the vapor to a higher pressure.

Based on driving energy. The driving energy refers to the energy that generates the motion of the working fluid from the low to the high-pressure side of the cycle. This energy can be sourced from process heat, steam, combustion, engines, or motors, depending on the technology and model.

Heat sources

Typical heat pump sources include air, ground (geothermal), water, solar-assisted, waste heat or a hybrid.

Air-source heat pumps (ASHPs) are subject to seasonal variation of ambient temperature. Their advantages are relatively low costs and ease of installation.

Ground (geothermal) source heat pumps (GSHPs) are subject to lower seasonal temperature variations, but at a usually higher initial cost than air source heat pumps due to the excavation required to reach the desired depths and install the piping needed to exchange heat with the ground.

Water-source heat pumps (WSHPs) allow for a higher temperature difference between the source and the sink, provided a significant water reservoir is nearby. Permitting requirements, freezing during winter, and limited geographical access to large volumes of water limit the use of these types of sources. However, their configuration can use hot water from other sources, such as process water, as described below.

Solar-assisted heat pumps combine the heat from another source with that from solar thermal collectors for applications such as water heating that require moderately higher temperatures.

Waste-heat heat pumps may use a variety of different heat sources, such as those available on industrial facilities. The temperature, quantity, and availability of different sources of waste heat will dictate the configuration, type of evaporator (for example, gas or liquid hot fluid), and working fluid to be used in the system.

Hybrid-source heat pumps combine different sources for either single or multiple applications.

Other configurations

Figures 3, 4 and 5 show single-stage configurations with one evaporator and one condenser. However, heat pumps can be configured in many different manners to improve performance, capture heat from different sources, deliver heat to different sinks, or deliver heat to higher-temperature differentials. Figure 6 shows some examples of different configurations of vapor-compression heat pumps:

- A multiple-stage heat pump where intermediate flash tanks are placed after each expansion stage to separate vapor going to compression from liquid going to the evaporator (Figure 6a)
- A cascade arrangement, where a low-temperature heat pump using one working fluid delivers heat to a high-temperature heat pump using another working fluid, which delivers heat to the sink. In this arrangement, the first loop's condenser acts as the second loop's evaporator (Figure 6b)
- Systems involving different evaporators to capture heat from different sources, such as geothermal, solar collectors and waste heat (Figure 6c)
- Systems involving different condensers to deliver heat to different sinks (Figure 6d)
- A reversible heat pump used for space heating during winter and cooling during summer, where the direction of the flow is reversed so that the evaporator and condenser switch roles depending on the ambient temperature (Figure 6e)

Operating ranges & refrigerants

Figure 7 shows typical operating ranges for commercially available vapor compression heat pumps

utilizing different compressor types and working fluids. These ranges are under continuous improvement, given research efforts into increasing the efficiency of the components, utilizing new solvents, or enhancing the system configuration. As an example, efforts are underway to increase temperatures, in order to enable heat pumps to reach industrial heating (for example, low-pressure steam) ranges.

When selecting refrigerants, aside from the pressure, temperature and efficiency considerations inherent to the system, other criteria to consider include toxicity, flammability, environmental considerations and cost.

The International Institute of Refrigeration estimates that R-22 and R-410A are currently "the main refrigerants used for ASHPs" [*3*].

R-22, along with other Hydrochlorofluorocarbon (HCFC) refrigerants, are being phased out due to ozone depleting potential. For instance, in the U.S., the production and import of R-22 and R-142b has been banned for new units since 2010, and for servicing of existing units since 2020 [*4*].

Hydrofluorocarbon (HFC) refrigerants are replacing HCFCs, but some of the options available also possess environmental concerns due to their Global Warming Potential (GWP). For instance, R-410A has a GWP of 1,924 [*5*].

Refrigerants such as ammonia or CO_2 are mostly used in industrial settings due to safety and pressure concerns. Propane is utilized in some refrigeration applications, especially in industrial settings where electrical installations comply with electrical area classification requirements.

There is wide research into developing non-toxic, low-GWP refrigerants, but many of these are flammable and thus subject to safety considerations. Different tables are available to compare their performance and characteristics, subdividing them into low, medium or high pressure, or into low, medium and high GWP.

Some of these newer refrigerants are marketed as direct replacements to their phased-out counterparts, which is especially important to maintain usage of equipment designed for the latter. When replacing the working fluid, it is always recommended to consult with the heat-pump supplier or service technician.

Heat-pump process design

Heat-pump design typically involves the following steps: 1) Defining the service heat load and temperature; 2) Assessing the sources for the heat pump; 3) Defining the design capacity of the heat pump; 4) Specifying and selecting the heat pump.

Step 1. The first step in designing a heat-pump system consists of identifying the required service (heating or cooling), heat load and temperature.

The temperature is defined in accordance with the required application. For instance, for space heating, the temperature is typically selected around the comfort temperature. Water heating or industrial applications typically require higher temperatures.

Step 2. The required heat pump load is calculated to maintain a net zero energy balance around the volume of the space or system receiving the service:

$$0 = Q_{heat\ pump} + Q_{heat\ sources} + Q_{transfers\ to/from\ environment} + Q_{process} \quad \mathbf{(7)}$$

Heat sources may include heat rejection from equipment, machinery or appliances, or heat emanated from occupants.

Heat transfers to and from the environment may include heat radiated from the environment (for example, solar radiation), heat losses to the environment (when the system is at a higher temperature than the environment), or heat gains from the environment (when the system is at a lower temperature than the environment).

Process heat encompasses other services used for process streams (for example, water heating or cooling, process cooling and so on).

These heat-pump requirements typically involve heating, ventilation and air conditioning (HVAC) calculations that consider space distribution, types of equipment or appliances, insulation, and other contributors to the heat-balance equation, as well as seasonal variations in heat loads and environmental conditions. Commercial or open-source tools are available to assess heating or cooling requirements.

In Equation (7), especially in space heating or cooling service, passive design features directly affect the heat requirements of the heat pump. Measures such as solar passive design and increased insulation reduce the heat pump requirement and are typically evaluated in an economic optimization study that seeks to reduce the overall cost of the service throughout the project life horizon.

The second step is to assess the available source(s) for the heat pump and determine its temperature and operating conditions. As discussed previously, heat sources may come from air, ground, water, waste heat or combinations. The evaluation of the heat source includes temperature profile (daily and seasonal), hot fluid phase (liquid, gas) and available heat (especially when considering waste heat, water, or ground sources, which may have flowrate or regeneration constraints).

Step 3. The next step is to define the capacity of the heat pump. The capacity is typically defined as a margin above the calculated heat load considering seasonal variations and is set at the worst condition for the expected service (for example, for an ASHP used for space heating, the heat pump capacity is defined by the minimum expected ambient air temperature and the maximum desired room temperature, and vice versa for space cooling).

Step 4. The heat-pump specification then comprises the required capacity, heat load evaluation, source type and temperatures. The specification may also include the heat-pump type, a desired minimum coefficient of performance, some technical, service and guarantee considerations, and a preference for working fluid (for example, a non-toxic, non-flammable, low-GWP refrigerant). There may be some tradeoff between the desired specifications (for instance, a low-GWP refrigerant may lead to a lower coefficient of performance or a higher cost than

a higher GWP alternative), so care must be taken to discuss with potential suppliers about the availability of suitable options.

Selection of the final device or system depends on adherence to the specifications by the potential suppliers, along with a tradeoff between capital and operating costs, and other technical aspects. Often, each supplier will quote the standard system within its catalog that will cover the service requirements in the specifications.

It is a good practice to evaluate different types of heat pumps (for example, comparing an air-source heat pump against a ground-source heat pump), given that higher initial capital costs may be compensated by reduced operations costs due to higher coefficients of performance. A lifecycle cost analysis (see Ref. 6) can be used to compare different alternatives to determine the minimum total cost over the system lifespan.

An example calculation

An industrial process requires 3,000 kW to raise the temperature of a stream to 45°C. Two alternatives are under evaluation: 1) use a natural-gas-fired heater with 80% efficiency; or 2) use a heat pump to transfer heat from a source at 24°C. The proposed heat pump is a closed one-stage vapor-compression cycle with an evaporator operating at 18°C and a condenser operating at 50°C. When reading the refrigerant properties at a pressure-enthalpy diagram similar to Figure 1, the following specific enthalpies are determined:

h_1 (evaporator outlet): 1,461 kJ/kg

h_2 (compressor discharge): 1,630 kJ/kg

h_3 (condenser outlet): 421 kJ/kg

h_4 (expansion valve outlet): 421 kJ/kg

The plant manager wishes to compare the annual energy expense of both options, assuming that the plant is required to operate 8,640 hours per year, and that the energy rates are $4 per million Btu ($0.014/kWh) of natural gas, and $0.04 per kilowatt-hour of electricity.

Option 1: Natural-gas-fired heater. For option 1, the fuel heat consumption is the heat load divided by the heater efficiency:

Fuel heat consumption, option 1 = 3,000 kW/0.80 = 3,750 kW

The total annual energy consumption is: 3,750 kW × 8,640 h/yr = 32,400,000 kWh/yr

The total annual energy cost is:

32,400,000 kWh/yr × $0.014/kWh = $453,600/yr

Option 2: Heat pump. For option 2, the electrical power consumption is the heat load divided by the coefficient of performance. To obtain the coefficient of performance, Equation (3) is rewritten to express the condenser heat rate and compressor power as the working fluid flowrate multiplied by the enthalpy difference in each equipment, assuming no losses in piping:

$$COP = Q_h/W = [m \times (h_2 - h_3)]/[m(h_2 - h_1)]$$

Where m is the mass flowrate of the working fluid.

Since the flowrate through the compressor is the same as the flowrate through the condenser, then for this configuration:

$$COP = (h_2 - h_3)]/(h_2 - h_1) = (1{,}630\ \text{kJ/kg} - 421\ \text{kJ/kg})/(1{,}630\ \text{kJ/kg} - 1{,}461\ \text{kJ/kg})$$

$$COP = 1{,}209\ \text{kJ/kg}/169\ \text{kJ/kg} = 7.154$$

Then, the electrical power consumption for option 2 is:

$$W = Q_h/COP = 3{,}000\ \text{kW}/7.154 = 419\ \text{kW}$$

The total annual energy consumption is:

419 kW x 8,640 h/yr = 3,620,160 kWh/yr

The total annual energy cost is:

3,620,160 kWh/yr × $0.04 kWh = $144,806/yr

This is significantly lower than the annual cost for option 1.

Concluding remarks

Heat-pump technology is mature, reliable and safe. It is an efficient means to provide heat to a growing number of uses at increasing temperatures. Savings in heating expenses in the long run often outweigh the initial capital investment of a heat pump over heaters. New working fluids are continuously being developed, first to replace ozone-depleting refrigerants, and currently to provide non-toxic, low-GWP, and ideally non-flammable alternatives to available refrigerants. ■

Edited by Gerald Ondrey

Acknowledgements

The author would like to thank Mr. Philippe Nellissen for sharing the figures of his authorship in this article, and Dr. John R. Abelson for his feedback to improve the article.

References

1. Secretary of Energy Granholm, Accelerating Cold Climate Heat Pump Technology and Adoption in the Midwest, January 26, 2022, www.youtube.com/watch?v=z5oeTxVpb2A
2. Nellissen, Philippe "Energy Efficiency in industrial processes – the role of heat pumps" European Heat Pump Association, February 6, 2015, Retrieved from: www.ehpa.org/about/news/article/energy-efficiency-in-industrial-processes-the-role-of-heat-pumps/
3. International Institute of Refrigeration (2021, January) "Air Source Heat Pumps for Space Heating and Cooling"
4. US EPA "Phasing out HCFC Refrigerants to Protect the Ozone Layer".
5. Fifth Assessment Report (AR5) of the IPCC (Intergovernmental Panel on Climate Change).
6. Giardinella, Sebastiano; Baumeister, Zabdyk and Baumeister, Alberto, Using Lifecycle Cost Analysis for Best Project Value, *Chem. Eng.*,December 2020, pp. 32–39.

Author

Sebastiano Giardinella is a visiting assistant research scientist and project engineer at the Illinois Sustainable Technology Center, Prairie Research Institute, University of Illinois at Urbana-Champaign (1 Hazelwood Dr., Champaign, IL 61820; Phone: +1-217-953-1424; Email: sg00@illinois.edu; URL: www.istc.illinois.edu) where he is involved in energy-storage and carbon-capture projects. He previously co-founded the Ecotek group of companies (www.ecotekgrp.com/en), where he has performed feasibility studies, corporate management, project management and process engineering consulting in projects for the chemical and energy industry. He is a project management professional (PMP), has a M.Sc. in renewable energy development from Heriot-Watt University, a Master's degree in project management from Universidad Latina de Panamá, and a degree in chemical engineering from Universidad Simón Bolívar. He has written technical publications for *Chemical Engineering* magazine and other international associations, and holds one patent for an energy storage system and method.

An Ounce of Prevention: Cybersecurity and the CPI

As the frequency and sophistication of industrial cyberattacks continue to rise, chemical companies can follow guidance from industry and government directives to help define their organization's specific cyber-risk profile

Matthew Baker and Rachel Ehlers
Baker Botts, L.L.P.

IN BRIEF

Cybersecurity risk is a key topic for all companies, due, in part, to recent high-profile incidents and a heightened focus from regulatory agencies. This is of particular importance to industrial sectors that use technology for automation, control and information storage. Critical infrastructure sectors have increasingly become the targets of cyberattacks and cyber espionage, and it is now even more imperative for organizations in the chemical process industries (CPI) to identify individualized cyber-risk profiles and ensure appropriate safeguards are in place relative to those risks. As the saying goes: an ounce of [cyber] prevention is worth a pound of [cyber] cure.

The rise of cybersecurity concerns

Though all industries face some degree of cyber risk, the chemicals sector carries unique vulnerabilities. Computer-based automated industrial control systems (ICS) are widely used by chemical plant owners and operators to manage and run their facilities. Malicious actors, be they nation states, business rivals or cybercriminals intent on blackmail, are deploying a range of tools — both new and old, common and extraordinary — to exploit vulnerabilities resulting from increased interconnectedness between operational technology (OT) and information technology (IT) systems (Figure 1).

Successful exploitation of these vulnerabilities can create business disruptions and inhibit the use of equipment. They can also result in the theft of proprietary information, such as chemical formulations, customer data or personal information, and ultimately cause significant damage — system damage, reputational damage or even physical damage or safety risks, depending on the process. Threat actors see CPI organizations as high-value targets precisely because of the potential cost, both financial and reputational, to the owner or operator should production stop or sensitive data be stolen.

Furthermore, although cyber incidents are becoming more sophisticated, the tools and tactics that attackers use to access systems remain relatively constant. Some of the most common attack vectors include: social engineering attacks, such as email phishing; exploiting unpatched software vulnerabilities; and compromising remote desktop protocols or other external-facing network ports. Nevertheless, a few troubling trends are emerging. For example, upon gaining access to a system, threat actors often spend considerable time dormant and undetected, often gaining intelligence on system architec-

FIGURE 1. The increasingly interconnected nature of CPI facilities and global enterprises can introduce potential vulnerabilities for cyber threats

ture and preparing sensitive data for exfiltration. In recent incidents, threat actors have sold stolen data outright to competitors. In other cases, the threat actors use the data as leverage for a ransom payment.

At the same time, the current regulatory framework intended to support the CPI against cyberthreats is under question. Critics argue that the Chemical Facility Anti-Terrorism Standards (CFATS), the federal regulations specific to the chemicals sector (which have not been updated since their adoption in 2007), do not adequately reflect the current risk landscape.

For example, there is nothing in the CFATS addressing email phishing campaigns. In fact, a 2020 audit by the U.S. Government Accountability Office (GAO) found that chemical facilities are more vulnerable to cyberattacks simply because they are relying on the outdated regulatory guidance [*1*]. A key issue identified by the audit is the lack of an actual process or structure to routinely review the guidance and update to reflect the current threat landscape. Relatedly, a key component of the CFATS program is third-party inspection and oversight, but the GAO similarly found that inspectors did not have adequate cyber expertise or training to properly identify deficiencies.

FIGURE 2. Chemical companies can be attractive targets for cyberattacks because of the potential for high-value ransom demands, including the threat of production disruption or sensitive data exposure

Specific risk profiles for the CPI

The chemicals sector is an essential part of the nation's infrastructure. As a result, owners and operators are a high priority for threat actors because of the perceived leverage in ransom demands due to high costs of production disruption or theft of sensitive data (Figure 2). Additionally, these types of attacks receive higher attention, which promotes the "Ransomware as a Service" business model that essentially sells malware to other groups.

In addition, CPI enterprises are becoming more automated, computer-dependent and interconnected. The sector has traditionally been slow to adopt new technological innovations, but digitalization measures are becoming more popular (for instance, digital twins of physical production assets and smart supply chains). Computer-based, automated ICS are widely used by chemical companies to manage and operate their facilities. Most CPI companies have internet-connected devices as part of their process-control systems to allow, among other things, instrument manufacturers to service devices remotely. These remote access points are a popular way for threat actors to gain access to a system. An added risk is the mixture of old and new equipment, which is common in CPI facilities. However, these technological modifications are often made incrementally, and there is not always a clear understanding of how updates in one area may affect other areas, which can lead to vulnerabilities.

Finally, the COVID-19 pandemic has created new cyber challenges for the sector. With the shift towards remote work and a distributed workforce across home networks and hot spots, company networks are spread wider than they have ever been, creating a host of vulnerabilities. As a result, there has been a correlative uptick in electronic messaging, which has led to an increase of phishing messages designed to look like official communications to persuade people to click on malicious links or enter credentials. Additionally, there are more platforms to allow interaction between remote experts and field personnel. And, as noted previously, some essential functions at the plant level, including service engineering, are now routinely done remotely through applications that are at risk of being compromised.

Despite these continued risks, organizations are also being asked to cut costs because of the economic downturn that has resulted from the pandemic. These cuts can have a substantial impact on operations, often requiring companies to choose between new initiatives to fund, potentially thwarting investment in preventative security.

Cyberattacks in the CPI

In 2017, one of the most well-known attacks in the CPI occurred, when a petrochemical facility in Saudi Arabia was attacked. The safety control systems that were in place to prevent a cyber intrusion were thought to be impenetrable. Fortunately, the attack was detected early, and the threat actor was unable to cause serious damage. Nevertheless, the potential for disaster was so great that the attack has been dubbed "the world's most murderous malware" because experts believe the attack was designed by a nation state actor (probably Iran) to trigger an explosion at the facility.

In 2019, three large chemical manufacturers — Norsk Hydro, Momentive and Hexion — were victims of ransomware attacks [*2*, *3*]. As a result of the attacks, the Norway-based global aluminum producer,

FIGURE 3. CFATS provides security guidance for high-risk facilities, which are designated based on the presence of so-called chemicals of interest, which include toxic, flammable or explosive materials

Norsk Hydro, was forced to shut down plants and switch to manual production after key systems were encrypted and inaccessible. Around the same time, U.S.-based chemical companies Momentive and Hexion announced they had also become victims of a cyberattack. The same encryption program is believed to be behind all three attacks, but investigators could not determine how the malware was introduced into the systems. Experts believe the three attacks were financially motivated.

Finally, in 2021, three other chemical manufacturers — Siegfried, Brenntag and Symrise — were victims of cyberattacks. Swiss drug ingredient manufacturer Siegfried experienced a malware attack that shut down production at multiple sites and cut off network connections [*4*]. Siegfried was involved in the packaging of the Pfizer COVID-19 vaccine at the time of the attack. Later in 2021, chemical distributor, Brenntag, was a victim of the same ransomware variant used in the Colonial Pipeline attack. Brenntag reportedly paid $4.4 million to the threat actors to recover potentially impacted data, including intellectual property, project data, financial information and employee data. Symrise was also the victim of a ransomware attack. The company reportedly did not pay the ransom but, according to the company's CEO, the resulting delays in production and logistics directly related to the cyber event caused the company to fall short of its sales targets.

Industry laws and standards

The chemicals sector is not without its guardrails. In addition to the CFATS, there are frameworks that support proper risk profiling and cyber preparation for the sector, as well as regulate the protection of personal information (for instance, customer or employee personal information).

Additionally, new directives are expected for the chemicals sector through the Infrastructure Investment and Jobs Act, which was signed into law in November 2021 [*5*].

On March 15, 2022, President Biden signed into law the Cyber Incident Reporting for Critical Infrastructure Act of 2022 [*6*]. It requires entities in critical infrastructure, which includes the chemicals sector, that experience a covered cyber incident to report the incident to the Cybersecurity and Infrastructure Security Agency (CISA), part of the Department of Homeland Security (DHS; Washington, D.C.; www.dhs.gov), within 72 h after the entity reasonably believes the incident occurred. Additionally, in the event a covered entity makes any ransom payment, the entity must report the payment to CISA within 24 h.

The new reporting requirements will not go into effect immediately. Instead, a proposed rule is to be issued by March 15, 2024, and then the Director of CISA is required to issue the final rule within 18 months of the issuance of the proposed rule. The proposed rule should include definitions of covered entities and covered cyber incidents. The new law also includes the creation of a Cyber Incident Reporting Council, aimed to increase cooperation and responsiveness of federal agencies to cyber attacks impacting critical infrastructure.

Additionally, CISA recently announced its focus on the chemicals sector, and that it also will continue to release new guidance directed at critical infrastructure that aligns with President Biden's cybersecurity executive order [*7*].

CFATS. The approximately 3,300 CPI facilities identified as high-risk because they possess certain quantities of designated chemicals of interest are covered under CFATS [*8*]. The CFATS are regulated under CISA and are meant to ensure that security measures are in place to reduce the risk of hazardous chemicals being weaponized. The CFATS regulations apply across the chemicals sector, including chemical plants, chemical storage facilities and electrical generating facilities. Facilities are required to report to CISA within 60 days of when they gain possession of one of the more than 300 identified chemicals of interest (Figure 3). CISA then determines whether the facility is high risk. High-risk facilities are then required to develop and implement a security plan that addresses the CFATS requirements, which include requirements for covered facilities to establish protocols for identifying and reporting significant cyber incidents to appropriate facility personnel, local law enforcement and CISA.

National Institute of Standards and Technology (NIST) Framework. The National Institute of Standards and Technology (NIST; Gaithersburg, Md.; www.nist.gov) cybersecurity framework [*9*] has been adopted by many CPI companies to create cyber-risk management programs. NIST establishes specific cyber frameworks for industrial control

systems that are organized into the following five key areas:

1. Assessment to identify organizational cybersecurity risks to systems, assets, data and capabilities
2. Safeguards to protect the organization, including access control, processes and procedures, protective technology and training
3. Detecting and identifying cybersecurity events
4. Cyber-incident response plans
5. Plans to recover and restore capabilities and services should there be an incident

ISA 62443. The International Society of Automation (ISA; Research Triangle, N.C.; www.isa.org) released standards that outline cybersecurity plans, processes and procedures for securing and defending industrial plants from cyberattacks [*10*]. ISA 62443 is focused on operational technology, rather than information technology, and it is not specifically tailored to the chemicals sector but does offer an approach to create a cybersecurity management system. Companies can seek ISA 62443 certification, which is a third-party technical expert attestation of compliance with the requirements. These include requirements related to engineering processes, product design and network susceptibility.

American Chemistry Council. The American Chemistry Council (ACC; Washington, D.C.; www.americanchemistry.com) requires its members to perform a risk assessment to review cyber vulnerabilities, implement security measures to address those threats, and provide training and guidance to employees on current and emerging threats. ACC members include companies involved in chemical manufacturing, sales, transportation, distribution, and storage and disposal.

Data privacy and protection laws. Should a company fall victim to a cyber incident, there is always a risk that sensitive personal data belonging to individuals could be impacted. There is no single U.S. federal law for data privacy and protection that comprehensively covers the chemicals sector, but every state has passed some form of data-breach response legislation, and many states have consumer protection laws of various types. About half of the states also have minimum technical and security requirements that companies are required to implement to protect data. In addition, California has a comprehensive data-protection regime through the California Consumer Privacy Act (CCPA), which went into effect in 2020. Since the passage of the CCPA, other states, including Virginia and Colorado, have adopted similar laws. Additionally, several countries and regions have adopted comprehensive data protection legislation, including the U.K., Brazil, South Africa, China, South Korea and Japan. The E.U., in particular, has long applied a more wide-ranging data-protection regulatory scheme, and its most recent data protection law, the General Data Protection Regulation (GDPR),

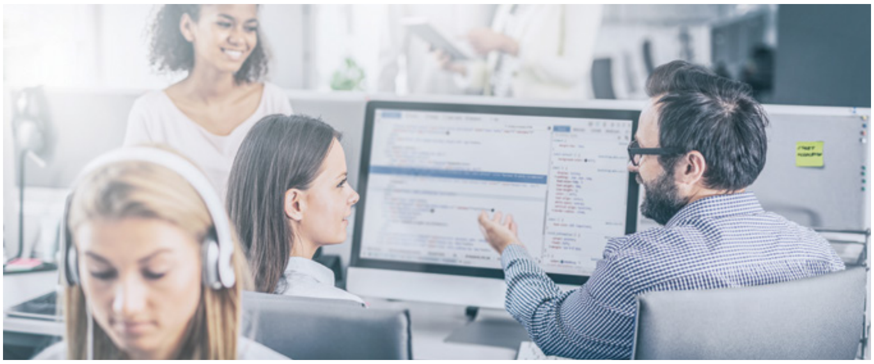


FIGURE 4. It is vital for companies to regularly train employees on cybersecurity and phishing issues

has served as a model for other jurisdictions developing robust data-protection requirements.

The ounce of prevention

Given the heightened risk of cyber incidents in the chemical sector, owners and operators should undertake specific steps to protect themselves from cyber vulnerabilities to help mitigate damage to systems and data should they fall victim to an attack.

Adopt a "zero trust" model. A zero trust approach is based on the premise that no source should be trusted, and cybersecurity teams need to assume that attackers are always present inside and outside of their networks. This drives the idea that no communication or activity should be allowed until it is first properly authenticated and authorized.

Zero trust also includes a focus on the micro-segmentation of networks, which unlike traditional network segregation that controls traffic into and out of a data center, is concerned with segmenting traffic moving between applications and processes. This may include separation of operational systems and data systems (for instance, the segregation of OT and critical processes from other business systems) and blackening certain infrastructure with deny-all firewalls and by providing no public IP addresses or open ports.

Foundational controls. Companies should have several foundational controls, including the following:

- Patching with automatic updates
- Encryption of sensitive data
- Offsite backups
- Multi-factor authentication (MFA)
- Malware protection
- An up-to-date anti-virus system
- A reputable firewall configured to block malicious IP addresses
- Application whitelisting
- Asset inventory

These types of controls allow companies better visibility into systems and networks, potential threats and related risk exposure and to identify where vulnerabilities might exist.

Monitor and detect. In addition to controls, companies should have detection capability and security operations to monitor the controls put into place. Companies must consistently review and appropriately respond to events within the network. Companies should perform regular vulnerability scans and should consider implementing an endpoint detection and response (EDR) solution.

Inform and respond. Companies should regularly provide cybersecurity and phishing training and exercises for all members of their organization (Figure 4). Companies should also have a robust incident-response and business-continuity plan, and regularly test both. Finally, chemical engineers and plant operators need to work closely and communicate regularly with the organization's technology and security teams, as the plant engineers may not understand technical or security issues and the IT or security teams may not understand the OT in the plant.

Key takeaways

Cybersecurity must be a key focus and an identified enterprise risk. The number of attacks continues to rise, and at the same time, the attacks are becoming more sophisticated. Regulators are also extremely focused on improving security in the CPI and updating guidelines — the sector must dedicate resources to track and implement these directives. All this is happening in a time when the CPI continues to automate and develop technologies that are more connected and pose more risk. Companies must update their strategies for preventing attacks — that way, if they do fall victim (and unfortunately it is often a question of when, not if) — they are better prepared to mitigate the damage and resume normal operation quickly. ■

Edited by Mary Page Bailey

References

1. U.S. Government Accountability Office (GAO), Actions Needed to Enhance DHS Oversight of Cybersecurity at High-Risk Chemical Facilities, GAO-20-453, May 2020.
2. Norsk Hydro, Updates on cyber attack, Press releases dated March 19–April 5, 2019 .
3. Bailey, M. P., Hexion and Momentive respond to cyberattacks, *Chem. Eng.*, March 25, 2019.
4. Bomgardner, M. M., Siegfried, Brenntag, and Symrise hit by cyberattacks, *Chemical & Engineering News*, May 27, 2021.
5. 117th U.S. Congress, Public Law 117-58, Infrastructure Investment and Jobs Act, November 15, 2021.
6. 117th U.S. Congress, H.R.2471, Consolidated Appropriations Act, March 15, 2022.
7. Cybersecurity and Infrastructure Security Agency (CISA), Cybersecurity Directives, www.cisa.gov/directives.
8. Lozowski, D., CFATS and Chemical Plant Security, *Chem. Eng.*, Sept. 2009.
9. NIST Cybersecurity Framework, www.nit.gov/cyberframework.
10. Cosman, E. C., Industrial Control Systems Security: The Owner-Operator's Challenge, *Chem. Eng.*, June 2014.

Authors

Matthew R. Baker (Email: matthew.baker@bakerbotts.com) is a partner at Baker Botts in San Francisco. His practice focuses on white collar defense, crisis management and internal investigations for a broad range of industries, with an emphasis on the energy and chemical sector. He is also well-versed in complex electronic discovery and information governance issues, as well as domestic and international data privacy and information security practices.

Rachel Ehlers (Email: rachel.ehlers@bakerbotts.com) is a special counsel at Baker Botts in Austin, Tex. Her practice focuses on technology transactions, data privacy and cybersecurity. She has extensive experience advising clients on data incidents and breach response, cross-border transfers, and data privacy and cybersecurity issues related to mergers and acquisitions.

Valve Actuator Selection Guide

Information provided here can help guide the selection of valve actuators that are best suited to the demands of a particular chemical processing application

Gilbert Welsford Jr.
ValveMan LLC

Actuators are machines used to control the position of a valve remotely and automatically. They are attached to the control mechanism of a valve to replace the manual lever or handle. Valve actuators are essential components in flow-control systems. The primary function of an actuator is to control the position of a valve. The actuator can close a valve, open a valve, move a valve to a specific position, hold the valve in place, prevent valve leakage by creating a tight shutoff, operate in failure mode, modulate flow through a valve and so on.

In industrial applications, numerous types of actuators are available, and they can be connected to a variety of valve types. Selecting the proper actuator for a given application is a task that must be considered seriously. Several factors influence the kind of actuator that is suitable for a process. This article is an all-in-one actuator guide that covers the essential function of actuators, outlines actuator types, and describes important considerations for valve-actuator selection for the particulars of an application.

Actuator operations

Actuators control valves through three standard valve operations: quarter-turn operation, multi-turn operation and linear operation.

The quarter-turn operation involves valves that rotate 90 deg from the closed position to the open position (for example, ball valves and butterfly valves). The actuator control on quarter-turn valves can be on/off or modulated. Actuators for these valve operations are usually easy to install and maintain.

On the other hand, multi-turn valve operation requires the actuator to turn the valve mechanism several rotations before moving the valve from the opened position to the closed position. The mechanism can be a rising non-rotating stem or a non-rising rotating stem. Examples of valve types with this operation include globe valves, gate valves and needle valves.

Some valves are opened and closed through the linear operation of the valve mechanism. Linear operation involves motion in a straight line (in contrast to the circular motion of quarter-turn and multi-turn valve operation, although some multi-turn valve operations have the same mechanism as a linear valve operation — for example, certain types of globe or sliding gate valves). Linear valve operation can be driven in a number of ways other than by an electric motor. Linear motion can also be achieved by mechanical, hydraulic, pneumatic or piezoelectric power sources.

Types of valve actuators

Two main types of actuators, based on their motion, are linear and rotary. However, actuators are generally defined by the source of power that drives the actuator. They can be sorted as the following:

1. Electric actuators (powered by electricity; Figure 1)
2. Pneumatic actuators (powered by pressurized air; Figure 2)
3. Hydraulic actuators (powered by fluid; either water or oil)

Electric actuator. Electric actuators use electrical energy — usually 24V, 110V, 230V, 400V, single- or three-phase, to drive an electric motor whose rotor is connected to the shaft/stem mechanism of the valve. The electric motor can be powered by alternating current or direct current. They are an energy-efficient, clean and quiet method of valve control. The electric motor may be connected to the valve mechanism through gears to increase torque or regulate speed. Electric actuators are available for both very small-sized applications, as well as for actuators on large valves in industrial applications.

FIGURE 1. The photo shows an electric actuator mounted to a carbon-steel three-way ball valve

Electric actuators are capable of relatively high speeds if needed, but they tend to be slow-reacting if standard-specification actuators are used. There is an option to install a positioner that converts an on/off actuator to a modulating actuator capable of precise flow control. However, if electric actuators are modulating constantly, the motors can burn out. Electric actuators often have a declutching mechanism to allow rotation of the drive during a power failure or installation. Emergency power can be provided through a battery to ensure a fail-safe operation.

A specific category of electric actuators is called linear actuators. They also convert electric energy from an electric motor to mechanical motion. However, the motion is not rotational to turn a valve, but to move a stem attached to a load or a valve in a linear direction. They are used in globe and gate valves and many other functions requiring linear motion of a load.

Pneumatic actuator. Pneumatic actuators are highly reliable actuators that are popular in industrial applications. They convert compressed-air

energy into mechanical motion and can be used in locations with no electricity. Pneumatic actuators are of two types: single-acting or double-acting. Single-acting pneumatic actuators use a single compressed-air source to turn the valve with a spring to return the valve to the normal position. A double-acting pneumatic actuator has two compressed-air sources that turn the valve and return it to the original position, otherwise known as a fail position.

Pneumatically controlled valves are relatively simple when compared to electric actuators — they are easy to install and maintain, and have a very fast operating speed. There is a cost benefit of using pneumatic actuators, but it only applies in valves up to a certain size.

Pneumatic actuators often use a cylinder with a mechanism that converts the linear motion from the compressed air into rotational motion. The most common mechanism is the rack and pinion, but it can also be a diaphragm, piston or scotch yoke. Most pneumatic actuators are used for quarter-turn valves. The mechanism can be spring-loaded to return to a normal shut-down position in emergencies.

Solenoid valves are used to regulate airflow into the actuator. Electrical signals from a controller energize the solenoid valve position to either open or closed, allowing compressed air to flow through to the pneumatic actuator's sides. It is important to note that, in order to actuate a valve with a pneumatic actuator, there must be a supply of clean, instrument-quality air, normally at 60 or 80 psi.

Hydraulic actuator. Hydraulic actuators convert hydraulic power to achieve mechanical work. They can be used for quarter-turn valves, such as ball valves, or multi-turn valves, such as globe valves. Hydraulic actuators consist of a cylinder and a mechanism for converting linear motion to rotational motion, such as a scotch yoke mechanism. Hydraulic actuators use high-pressure oil from a hydraulic pump to drive the valve.

Like pneumatic actuators, hydraulic actuators can be single-acting, with a spring as a fail-safe, or double-acting. They are relatively small compared to pneumatic actuators, but with thicker parts due to the high-pressure operation. They are also more precise than the pneumatic actuators because oil is incompressible. Hydraulic actuators are commonly used in large valve sizes that require a large turning force.

Actuator selection criteria

Before purchasing an actuator, several basic parameters should be considered. These parameters are based on the function for which you will use the actuator, as well as the environment. However, some actuators have unique features in addition to the basic parameters, which makes them unique. Always read the manufacturer's documentation for recommendations and features of each actuator.

Presented below is a list of important parameters that should be considered when deciding on which actuator would be most suitable for an application.

Operating conditions. The actuator's operating conditions and environment go a long way toward determining what type will fit best for your application. Operating conditions can include the following:

Temperature: Electric actuators can overheat if the operating temperature is too high. Pneumatic actuators are more commonly used and best suited for high-temperature operations.

Pressure: While all actuator types can operate at high pressure, consider the pressure differential across the valve, which will determine the amount of required torque for the actuator to turn the valve.

Hazardous environment. Make sure to select the actuator and actuator accessories with the correct IP code (ingress protection code against intrusions) if your environment has dust or moisture. Electric actuators with IP 67 and below are vulnerable to damage from moisture and condensation. Pneumatic actuators are preferred in wet environments. If the actuator operates in an explosive environment, one must consider whether the subject actuator meets a specific explosion protection standard, such as those that carry an explosion-proof NEMA rating or a flameproof ATEX classification. Another thing that must be considered is the duty cycle. Establishing an accurate duty cycle can help to decide which actuation mechanism should be used for a specific application. An electrically actuated valve can provide reliable service for a piping system that operates a few times a day. However, as the frequency of operations increases, and with it, the duty cycle, the electric actuator may suffer from burnout due to motor coils heating up. Pneumatic actuators are the most suitable choice for applications that require frequent valve operations as they can handle high-frequency duty cycles without failure.

Connection type. Consider that actuators have different connection types based on various standards. In order for the actuator to be connected to the valve, specific adapters must be used so that it may be mounted on the valve stem properly and perform its function as expected.

Consistency. While sometimes not obvious, the simplest way to decide which actuator is suitable for your application is by checking to see what type of actuators are already in use in the process.

Control functions. The type of control the process requires, either on/off or modulating, will determine whether the actuator requires a positioner or end switches. Consider the type of signal that will be sent to achieve this control. There are digital signals for on/off controls and various types of analog signals for modulating flow control.

Sizing. The actuator should be sized according to the torque requirement. It is quite common that manufacturers supply both the actuator and valve as one unit. When you already

FIGURE 2. **The pneumatic actuator shown here is attached to a two-way ball valve made of brass**

have a valve and want to select an actuator, check for the size range to fit the mounting flange and the valve's minimum torque requirement. This information is available in the valve documentation.

Torque. When deciding the valve's torque, consider the minimum torque required to start motion (otherwise known as breakaway torque) when the valve is at rest on the valve seat and the torque needed to close the valve into the valve seat completely. The actuator torque should be some percentage — usually 10–30% — higher than the minimum torque required from the valve.

Frequency of use. Some actuators are designed for on/off positions with limited use frequency, while others are designed for continuous modulation throughout their working life. Consider the control function in your process before deciding what type of actuator will be the best fit. The frequency of use directly affects an actuator's durability as the actuator is a mechanical device that wears with use. This is particularly crucial for modulating valves that may be constantly operated and could overheat or fail.

Operating speed. Actuators can be fast-acting, closing a valve from a fully open position in a few seconds, or slow-acting, which takes several minutes. The particular process application will determine what kind of actuator speed you need. For example, a ventilation actuator in a building will be slow-acting because its thermal mass will prevent quick temperature changes. On the other hand, a hot-water supply line in a brewery will be fast-acting to ensure precise flowrate and volume is distributed for the brewing process.

The speed of an actuator is also directly related to the power used by the actuator during operation. The more the speed that is required, the higher the power rating. For electric actuators, this defines the electric motor power and gear system, while for pneumatic and hydraulic actuators, it defines the actuator's operating pressure and size. When choosing the operating speed of an actuator, it is crucial to make sure that the valve is not closing too fast. Closing the valve too quickly may lead to a hydraulic shock to the system, which may result in damage to the connected pipes and equipment.

Ease of operation and maintainability. Pneumatic actuators are the easiest to install and maintain because they have very few parts and a simple operation mechanism. Electric actuators can be sophisticated and may be the most difficult to troubleshoot when they do not work. Pneumatic and hydraulic actuators are also very durable when compared with electric actuators.

Available power source. Sometimes, the choice of an actuator type is strictly determined by the available power source within the valve environment. Electric actuators can be powered by 24-V, 110-V, 230-V, 400-V, single- or three-phase power, and by direct or alternating current. Pneumatic actuators require compressed air between 60 to 150 psi (4–10 bars), while hydraulic actuators could have the oil operating pressure at 2,900 psi (200 bars).

Failure mode. If the valve is required to be at a particular position when there is a sudden loss of power source, a fail-safe mechanism is needed. Pneumatic and hydraulic valves can have a spring-loaded actuator that returns the valve to a default position, while electric actuators have a battery. They may also have springs for fail-safe operation. This adds to weight, size and cost. The fail-safe functions can be one of the following: close at no power, close at no control, open at no power and open at no control. When adding a fail position in a pneumatic or hydraulic actuator, the actuator must be upsized. Now, the actuator is overcoming not just the torque of the valve, but the spring's pressure as well.

Available space. A pneumatic actuator can be significantly bigger than the valve it controls, especially for low compressed-air pressure applications. Check that available space can accommodate a particular actuator type before final decisions are made.

Actuator cost. Regardless of an actuator's suitability to your application, the cost is often a determinant of the type of actuator selected. The higher the torque, power, size, extra features like ATEX, positioner, and so on, the higher the actuator's cost will be. While certain features can be avoided to reduce cost, others, such as torque and power requirements, cannot be compromised.

Selection process

The starting point for the actuator selection is always the question, "What function will the actuator perform in your process?". After this is clearly determined, take care to go through the selection criteria one after the other to ensure that all have been considered before selecting the type of actuator, as well as its size, and the features applicable within your budget.

The selection process for the right valve actuator can be complicated. Sometimes, existing infrastructure, such as power sources, communication modules, distance to the control room, as well as the experience of the engineer, can play a significant role in the decision-making process. In other situations, valve-actuator selection is done first with few desired specifications and other parameters have to be created to support the operation of the actuator.

The ultimate purpose of a valve actuator is to perform a certain operation, or series of operations, in the most cost-effective way possible, while automating the process. There are many features to consider when selecting a valve actuator, but remember that these features will affect the quality and cost of the actuator. Any additional torque capacity beyond the specification, or an ATEX approval or a positioner, may not be needed for your application. Leaving them out can save you quite a bit of money. If needed, consult a valve engineer to assure the sizing and selection has been done correctly for your specific application. ■

Edited by Scott Jenkins

Author

Gilbert Welsford Jr. is the founder of ValveMan.com (310 Commerce Drive, Exton, PA 19341; Phone: 484-713- 0065; Email: editor@valveman.com) and a third-generation valve entrepreneur. Welsford has learned valves since a young age and has brought his entrepreneurial ingenuity to the family business in 2011 by creating the online valve store ValveMan.com. Welsford's focus is building on the valve business legacy his grandfather started, his father grew, and he has amplified. Welsford holds a B.A. in business management from James Madison University. He has over 15 years of experience selling valves, and is a published writer in industry-leading publications focused around the valve industry.

Why Innovation Operations are Critical

The future of the CPI depends on sound innovation. The guidance provided here will help organizations to shape an effective innovation strategy that can give them a competitive edge

Chris Townsend
Wellspring

You would be hard-pressed to find a company in the chemical process industries (CPI) that isn't proud of its history of innovation. And for good reason, as responsible chemical innovation has done wonders for agriculture, home goods and many other industrial categories — not to mention countless everyday products (Figure 1). Yet for all of the good work being done, too many chemical companies are missing promising opportunities for future success when it comes to their critical innovation practices.

It's not that the existing innovation processes are broken — but they're no longer sufficient. From bioplastics to alternative fuels, the chemicals industry is moving steadily into uncharted waters. Without the proper innovation strategies and infrastructure in place, traditional CPI companies will increasingly struggle to keep pace with promising (and well-funded) upstarts. Although it may be tempting to treat the pandemic-induced business shock as a one-time occurrence, a growing number of experts are pointing to the 2020s as an 'exponential age,' where such dislocations will be much more frequent. Therefore, even if these prognostications are incorrect, now is the time for organizations to learn how they can innovate more effectively.

The good news is that CPI companies still have vast resources and internal knowledge that, when channeled correctly, can snowball into tangible innovation gains. They just need the strategies and tools to help them do so.

This article provides practical guidance on how CPI companies can revamp their innovation operations, outpace competitors and surpass existing boundaries.

FIGURE 1. The continued development of innovative chemical products and processes has been paramount to the success of CPI companies

Build a strategic portfolio

Most companies devote the vast majority of innovation resources to incremental opportunities, driving key improvements into current products, technologies and markets. This occurs for two reasons. First, the corresponding innovation practices are well-understood — as an example, every chemical company knows how to run a new product development (NPD) process. At both the team and executive level, there is comfort in repeating what is familiar. Second, incremental innovation is predictable. By focusing on well-defined opportunities in well-understood markets, the organization can calculate both the likelihood and magnitude of success. It is much easier for financial officers to invest in innovation projects where the expected returns can be modeled with relative precision.

Unfortunately, as has been observed, there are looming challenges facing the CPI that are decidedly non-incremental. That means that CPI companies must learn how to invest and manage their innovation portfolio at a strategic level. The good news is that this is not as difficult as it may seem at first glance.

The first step is to separate your organization's innovation strategy out from its corporate growth plan. Most companies focus their planning efforts on business and market conditions as they exist today: known competitors, current products or existing customer segments. Although a good innovation strategy does address these incremental opportunities, it must also account for exploratory activities — those that anticipate the advent of technologies, markets and competitors that do not yet exist. Therefore, innovation strategies need to be much broader than typical short- to medium-term corporate growth, and they also need to be assessed and measured differently as well.

From there, it is imperative to put the right person in charge of the innovation strategy-setting effort.

Most companies tend to opt for the CEO or other high-level leadership personnel to set strategic prerogatives. The problem with this approach is that most organizations don't have a CEO that has the bandwidth or research and development (R&D) experience to drive non-incremental innovation. This is why the creation of the chief innovation officer (CINO) title (or an analogous role) is the next logical step. Dedicated solely to pushing non-incremental innovation forward, CINOs can serve as not just a qualified head of a company's innovation apparatus, but also as the key link between innovation and other corporate functions so that everything is moving forward in a cohesive manner.

The next requirement for building a robust innovation portfolio is finding a way to make innovation strategy both a top-down and bottom-up operation. Being top-down has obvious benefits, because senior leaders are in the best position to assimilate all relevant information into a comprehensive view of where disruptive threats and opportunities are most likely to emerge. But being bottom-up is equally important, as collecting new information is a never-ending quest, and the most vital innovation insights often originate on the front lines. Moreover, the strategy needs to be iterative as well, given that the impact on innovation strategy can be sizable as new information streams in. Imagine, for example, that a company has placed an innovation bet on cold fusion becoming a mainstream energy source. If the technological paths to implementation dry up, perhaps because research on an enabling component doesn't pan out, then the innovation strategy must pivot.

Nonetheless, allowing for pivots does not mean the innovation strategy should be flimsy — indeed, far from it. The goal is to set long-term priorities and then stick with them over the mid- to long-term. That means it is critical to correctly size the design and scoping of innovation priorities. At an exploratory stage, companies must avoid "too big to fail" initiatives, but they should also make sure that the guardrails for a given objective are broad enough to allow for a range of possible end-state outcomes. If managed well, it is unlikely that any piece of the innovation portfolio would suddenly shift from all-in to full-stop. The best practice is to incubate speculative bets somewhere in between those extremes, by tweaking and pruning resource allocation, depending on the evolving likelihood that a certain technology, societal trend or asset class will find a path to real-world impact.

A metrics-driven approach

Businesses today are smarter than they have ever been. Yet for as much as we talk about innovation, many companies do not have the proper measurement tools in place to evaluate whether innovation projects are moving in the right direction, need to be tweaked or should be abandoned altogether.

When setting measurements, it is important that innovation's key performance indicators (KPIs) don't blindly follow the same methodologies used elsewhere in the business. For example, although net present value (NPV) is a fabulous tool for assessing expected value from capital investments, it is not built to predict the return from long-term innovation projects. And the same shortcomings apply to nearly every other traditional metric in corporate finance because they all assume a fixed and knowable world that can be calculated through direct observation, while, when it comes to innovation, the exact opposite is true.

Measuring innovation properly requires embracing its inherent uncertainty. In making investment decisions, instead of expecting precise calculations for return on investment (ROI), leaders must grow accustomed to thinking in terms of strategic options (Figure 2).

On a project-by-project basis, it is helpful to measure intermediate success based not only on the strategic beneficial gains to be realized, but also on directional progress relative to time and effort. Innovation's job is to incubate exploratory bets until they have been de-risked and can be evaluated more like conventional capital investments. If the end game for a given innovation bet remains impossible to define, then innovation

FIGURE 2. When considering innovation opportunities, the investment evaluation metrics may require more strategic considerations than those that rely on precise calculations

FIGURE 3. A collaborative approach to innovation governance is crucial, and cross-functional teams can help deliver the most promising outcomes

efforts have not (yet) progressed very far. As exploratory efforts gain structure and definition, the possible risk-return curve begins to materialize. In this way, the exclusion of non-viable options can be just as valuable to the company as the creation of actual new-to-world innovations.

Interestingly, one of the most common issues with innovation metrics used by companies is about measuring the outputs. Unlike the expected-value planning measures discussed above, here we are talking about actual, tangible results. Companies may think this is easy and straightforward for innovation. However, there remains one large problem — innovation efforts, especially exploratory innovations, typically pass through many teams on their way to final launch or implementation.

In a globally diversified company, there may be dozens of different R&D and engineering teams that might decide to implement an artificial-intelligence (AI)-driven design capability, for example, either in whole or in part. Perhaps the AI piece is one component of a broader effort to improve their team's efficiency. If they make a raft of changes and productivity improves by 32% — how much of that success is attributable to the AI-derived capability in particular? Such questions are answerable, but since the team that benefits is more interested in the end-result of boosting efficiency, they may not be overly interested in tracking back to figure out the answers about how.

To overcome these hurdles, the key is to drive the company's innovation portfolio with strategic purpose from the outset. If leadership knows that AI-driven design is a strategic option the company plans to create or protect, then the organization will be primed not only to adopt it if and when the innovation bears fruit, but also to help measure the value it has driven throughout the organization, thus making measurement a priority, not an afterthought. The good news is that while this may seem like a far cry from the way organizations currently handle their innovation work, it is fundamentally no different than how every department participates in the annual budget season, or other traditional business-reporting functions.

Governance is key

One of the foremost reasons why companies fall short in their innovation aims is that the executive suite is often detached from their on-the-ground innovation workforces. This simply is not a blueprint for innovation success. Modern innovation operations practices bear fruit when there's a hands-on approach to innovation governance (Figure 3).

The reason is simple: the more promising the innovation, the more cross-functional the effort. Delivering gamechangers requires the input and assistance of various teams across the organization. If it is a new product technology, for example, then the engineering team must learn to incorporate it into the product design, and the manufacturing unit must learn to make it at scale, while the sales team must learn to sell it to customers, and the services group must learn to support its use. If any of these functions is too distracted or isn't fully bought in, the effort will fail. The problem is that many innovations — especially the most valuable ones — tend to "break the frame" of prevailing incentive structures, pricing schemes, supply chains and other established processes a company may have in place. Therefore, without executive intervention from the top, the organization will miss out on such opportunities. Unfortunately, this is all too commonplace at many companies today.

That said, this does not mean that everyone across the company needs to have a "drop everything and innovate" mentality in their daily work. However, when gamechanging innovations do traverse the pipeline stages all the way from exploratory work and into production, organizations need to be ready for them. Companies can help their teams get ready to "catch" the biggest, most promising innovations by first learning to accept smaller opportunities, of the kind that are more common and that also tend to get held up due to disorganization or mismatched incentives.

If the company treats each innovation project like a special case, then portfolio governance quickly becomes a massive challenge. But not every initiative needs constant scrutiny. Most of an innovation team's work happens in the background, as they incubate early-stage opportunities and try to turn them into value-creation

engines. Beyond the strategy-setting described above, a critical piece of the CINO's job is to determine when burgeoning successes are ready to appear before the executive committee.

Companies that do this well tend to have some type of innovation steering group that meets on a regular cadence, perhaps quarterly or biannually. It must be composed of senior executives who can make organization-wide decisions and thus "clear the path" when necessary. Its members must be aligned on the broad strokes of the innovation strategy, and beyond that, they must be able to trust innovation teams to incubate the right options as they explore the strategic priorities.

The new growth imperative

Formalized corporate-innovation programs often get a bad reputation. Some people view them as nothing but theater. Others view them as redundant with R&D or strategy or information technology efforts. And others take the cynical view that, although focusing on innovation is a good idea in concept, it can never work in practice because corporations are too slow and bureaucratic to innovate as effectively as startups.

Of course, there may be a kernel of truth in each of these viewpoints at each organization, but that does not mean full-scale corporate innovation is necessarily "dead-on-arrival." Indeed, it can't be that way — at least not if today's CPI companies want to retain their status as industry incumbents. Furthermore, research data and hands-on experience show that some large companies already know how to succeed in driving strategic innovation at scale.

Thankfully, the barriers to action come down to focus, persistence and leadership. Driving a world-class innovation-operation practice does not need to break the bank, it just needs to better coordinate many of the efforts that are already underway within a given company. Furthermore, it doesn't need to side-track the company from any of its shorter-term objectives — at least not if managed with the right strategy, the proper metrics and sound portfolio governance.

Despite all the change and uncertainty swirling in the CPI today, the future is very bright indeed, especially for those firms that are prepared to innovate with purpose. ■

Edited by Mary Page Bailey

Author

Chris Townsend is chief marketing officer of Wellspring, a provider of Innovation Ops software and solutions for corporations, universities and government agencies (954 W. Washington Boulevard, Suite 750, Chicago, IL 60607; Email: chris.townsend@wellspring.com). He has a B.S. degree in biology from Harvard University and previously held marketing roles within Inova Software and Imaginatik.

Economic Indicators

2020 2021 2022

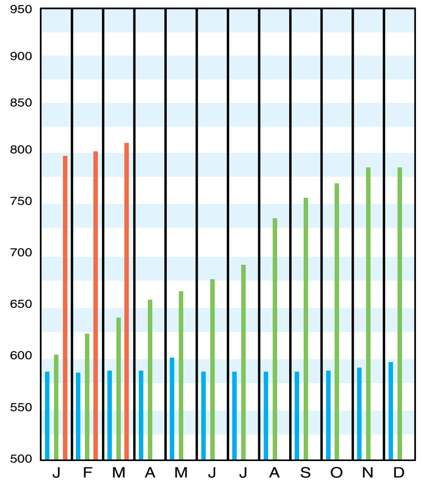
Download the CEPCI two weeks sooner at www.chemengonline.com/pci

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Mar. '21 Prelim.	Feb. '21 Final	Mar. '20 Final
CE Index	806.9	801.3	655.9
Equipment	1022.7	1015.3	808.5
Heat exchangers & tanks	861.3	859.0	698.5
Process machinery	1014.8	1007.8	792.5
Pipe, valves & fittings	1478.7	1470.3	1094.3
Process instruments	562.7	558.1	474.6
Pumps & compressors	1242.8	1226.9	1111.9
Electrical equipment	745.6	726.9	586.3
Structural supports & misc.	1128.2	1118.8	877.3
Construction labor	347.0	345.5	333.9
Buildings	829.5	826.0	678.7
Engineering & supervision	312.8	310.3	310.2

Annual Index:

2013 = 567.3
2014 = 576.1
2015 = 556.8
2016 = 541.7
2017 = 567.5
2018 = 603.1
2019 = 607.5
2020 = 596.2

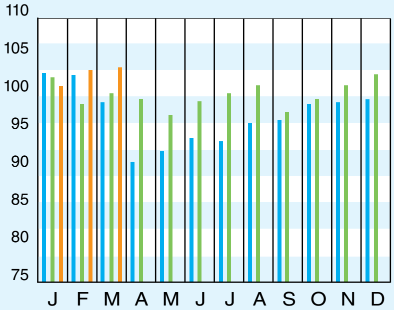


Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)

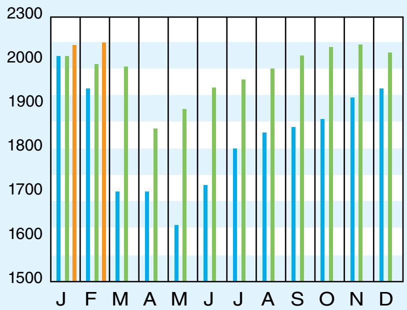
CURRENT BUSINESS INDICATORS

CURRENT BUSINESS INDICATORS	LATEST	PREVIOUS		YEAR AGO
CPI output index (2017 = 100)	Mar. '22 = 100.9	Feb. '22 = 100.8	Jan. '22 = 99.0	Mar. '21 = 94.3
CPI value of output, $ billions	Feb. '22 = 2,168.1	Jan. '22 = 2,140.2	Dec. '21 = 2,108.0	Feb. '21 = 1,799.8
CPI operating rate, %	Mar. '22 = 80.3	Feb. '22 = 80.2	Jan. '22 = 78.8	Mar. '21 = 75.2
Producer prices, industrial chemicals (1982 = 100)	Mar. '22 = 353.0	Feb. '22 = 341.5	Jan. '22 = 336.3	Mar. '21 = 280.3
Industrial Production in Manufacturing (2017 =100)*	Mar. '22 = 102.6	Feb. '22 = 101.7	Jan. '22 = 100.5	Mar. '21 = 97.8
Hourly earnings index, chemical & allied products (1992 = 100)	Mar. '22 = 196.8	Feb. '22 = 195.1	Jan. '22 = 193.8	Mar. '21 = 192.6
Productivity index, chemicals & allied products (1992 = 100)	Mar. '22 = 92.9	Feb. '22 = 93.4	Jan. '22 = 94.9	Mar. '21 = 87.4

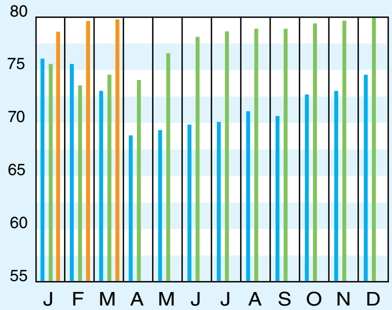
CPI OUTPUT INDEX (2017 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2012 to 2017
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the *CE* Plant Cost Index (CEPCI; top) for March 2022 (the most recent available) rose compared to the previous month. However, the final CEPCI value for February 2022 was revised downwardly from its initial value. In March, all four of the major subindices (Equipment, Construction Labor, Buildings and Engineering & Supervision) were slightly higher in March than the previous month. The current CEPCI value now sits at 23.0% higher than the corresponding value from March 2021. Meanwhile, the Current Business Indicators (middle) show small increases in the CPI output index and the CPI operating rate for March 2022, and a small increase in the CPI value of output for February 2022.